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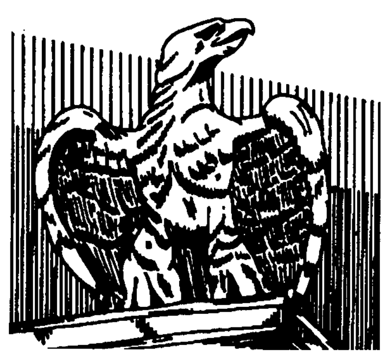
Evaluation of Technologies for Addressing Factors Related to Soil Erosion on DOD Lands

The Department of Defense (DOD) is currently moving towards the concept of "ecosystem management" to more effectively protect, sustain, and/or enhance natural and cultural resources critical to the training mission. Ecosystem management is an approach to natural resources management that recognizes the interrelationships of ecological processes that link soils, plants, animals, minerals, climate, water, and topography as a living system. This system is important to and is affected by human activity beyond traditional commodity and amenity uses and acknowledges the importance of ecosystem services such as water conservation, oxygen recharge, and nutrient recycling. Some of the factors that must be considered in ecosystem management include the effects of soil erosion on water and air quality, potential damage to wildlife habitat, and in the case of DOD, the effects on the ability to train efficiently and effectively. This study began to define a portion of the critical steps that DOD must accomplish to effectively and efficiently implement an ecosystem-based management program.



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Foreword

This study was conducted for the Office of the Directorate of Military Programs, Department of the Army with funding through the Legacy Resource Management Program Legacy Project 94-0784, under Military Interdepartmental Purchase Request (MIPR) No. W8IEWF43400079, dated 21 December 1994. The technical monitor was Jerry Williamson, SFIM-AEC-EQN, on detail from the Natural Resources Conservation Service to the Army Environmental Center.

The work was performed by the Natural Resource Assessment and Management Division (LL-N) of the Land Management Laboratory (LL), U.S. Army Construction Engineering Research Laboratories (USACERL) in collaboration with the U.S. Army Engineer Waterways Experiment Station (WES). The principal investigator was Dr. David L. Price. Participants in the study and report preparation were: Scott A. Tweddale and Dr. Steven D. Warren, CERL; Dr. Lawson Smith, Dr. Rebecca Seal, and Michael Waring, WES; Tony Palazzo, U.S. Army Cold Regions Research and Engineering Laboratory (CRREL); and Kevin Slocum, U.S. Army Topographic Engineering Center (TEC). Dr. David J. Tazik is Acting Chief, CECER-LL-N; Dr. William D. Severinghaus is Operations Chief, CECER-LL; and William D. Goran, CECER-LL, is the responsible Technical Director. The USACERL technical editor was William J. Wolfe, Technical Resources.

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1 Introduction

Background

The Department of Defense (DOD) is currently moving towards the concept of "ecosystem management" to more effectively protect, sustain, and/or enhance those natural and cultural resources that are critical to the training mission. Two of these natural resources, soils and water, have long been recognized as some of the most important and easily abused. Arakeri and Donahue (1984) stated that "... without them there would be no animals nor people. Managed for *long-term* productivity, there can be abundance for everyone; managed for *immediate* profits, soils will become impoverished and erode, waters will disappear as in a desert, and plants will wither and die." Traditionally, these resources were managed primarily from a single species/single resource perspective. While generally effective for the species or resource of concern, this approach often resulted in conflicting management objectives and uses that were not necessarily in the best long-term interest of the ecosystem as a whole. The dust bowl of the 1930s provided an excellent study in the consequences of single resource management practices and helped to focus national attention on soil conservation. However, soil conservation is much more than just controlling soil erosion; it also includes integrating many factors with sound land use and treatment (Konke and Bertrand 1959).

The advent of the concept of ecosystem management brought an increased awareness of the complex interactions among soils, water, wildlife habitat, and human activities. Ecosystem management is an approach to natural resources management that recognizes the interrelationships of ecological processes that link soils, plants, animals, minerals, climate, water, and topography as a living system. This system is important to and is affected by human activity beyond traditional commodity and amenity uses and acknowledges the importance of ecosystem services such as water conservation, oxygen recharge, and nutrient recycling (U.S. Air Force 1993).

Some of the many factors that must be considered in ecosystem management include the effects of soil erosion on water and air quality, potential damage to wildlife habitat, and in the case of DOD, the effects on the ability to train efficiently and effectively. The cumulative environmental impacts of poor planning yield a

litany of land use management "crises," from the degradation of water quality to the loss of wildlife habitat (Decker 1991). For example, the major source of suspended material in forest streams is erosion, resulting in high turbidity and sedimentation that can harm aquatic communities by affecting reproduction, respiration, and photosynthesis, and by interrupting the food chain. Turbidity and sedimentation also affect human use of water (Wenger 1984).

Under the auspices of the Tri-Services Reliance Program, the Army has taken the lead in developing general guidance and ecosystem management protocols, with the understanding that the individual Services may need to make minor modifications to address their specific policies. Components of the ecosystem that were identified as having the highest priority from a policy perspective included: water quality, soil stability, native biological diversity, and the integrity of cultural resources. In August 1994, the Office of the Directorate of Environmental Programs (ODEP) for the Department of Army requested the Corps of Engineers research laboratories to undertake a study addressing soil stability and its related effects on water quality. The study was a modification of Legacy Project 94-0784, Information Standards for Conservation Decision Making. The research laboratories include: the U.S. Army Waterways Experiment Station (USAWES), the U.S. Army Construction Engineering Research Laboratories (USACERL), the U.S. Army Cold Regions Research Laboratory (CRREL), and the U.S. Army Topographic Engineering Center (TEC).

Objectives

The purpose of this study was to begin to define a portion of those critical steps that DOD must accomplish to effectively and efficiently implement an ecosystem-based management program. Knowledge of the extent and condition of the resources is paramount to being able to allocate limited dollars and personnel to restore, enhance, and maintain the land to support training activities.

Approach

A multi-tiered approach was used to identify the best available technologies for each soil-erosion issue and to develop a consensus among the various Federal agencies on how those technologies can be used to address DOD-specific needs. As a first step in the tiered approach, each of the Corps Laboratory points of contact (POCs) surveyed their respective organizations for recently completed or on-going work that might be applicable to this project. Fact sheets on each of the technologies were assembled at each of the labs and then evaluated by the POCs for applicability and

feasibility. The most promising technologies were presented to a group consisting of the POCs and representatives from ODEP, the Army Environmental Center (AEC), Forces Command (FORSCOM), and the National Guard Bureau (NGB). The group concluded that many of the basic tools and technologies are available, but that they contain significant gaps, especially as they apply to DOD-specific problems.

The second step in the approach was to determine what tools/technologies were available or being developed at other DOD laboratories and technical centers. This was accomplished through a telephone survey of key headquarters personnel at the Departments of Navy, Marine Corps, and Air Force. It was determined that very little work was being done in those areas that was applicable to this project. Most of their needs were being met either by the on-going erosion work at the Army labs, or by work in other Federal/State agencies and academia.

The third and perhaps most important step in the approach was an Interagency Workshop held in San Antonio, TX, 11-15 June 1995. The workshop included key representatives from other Federal agencies, all services within DOD, and from several State and private organizations. The purpose of the workshop was to elicit information about available technologies under development at the other agencies and how those technologies could be applied (with or without modifications) to DOD installations.

Scope

The study was limited to issues related to the measurement and prediction of soil erosion, sedimentation and turbidity, and botanical composition as it affects the erosion process. Specific objectives were to identify and develop an interagency consensus on the best available technologies for addressing each of these issues. In this context, "best available," refers to the most feasible, advisable, and affordable technology based on both common sense and scientific validity. This study was not meant to advance the state-of-the-art in erosion technologies, but rather to provide a foundation from which to develop policies for management and to identify limitations in current technologies specific to DOD requirements.

2 Soil Erosion Prediction

Understanding the *potential* soil erosion that may result from an activity is critical to the management of natural resources on Army installations. Because soils are the foundation for many other resources, particularly plants, animals, and water, it is imperative that an accurate and appropriate estimate of the impact of military activities on soils be determined. Fortunately, the development of methods and procedures to estimate or predict soil erosion as a function of a wide range of land uses and conditions has received much attention by researchers in soil and water resources management. In this Chapter, the existence and applicability to DOD use of soil erosion prediction/estimation methods, models, and procedures will be discussed. After a review of the state-of-the-art in soil erosion prediction, recommendations are offered on the application of existing technology to DOD issues in soil and water resources management. This discussion begins with a summary statement of the issues that provide a need in DOD to apply soil erosion prediction technology on its installations. Additionally, the goal and objectives of the part of the project focusing on soil erosion potential will be stated.

DOD Requirements in Soil Erosion Prediction/Estimation

DOD is bound by a number of laws, policies, and accepted practices to manage its soil and water resources. Central to the broad challenge of responsible stewardship of soil and water as well as other natural resources is the prediction/estimation of soil erosion potential. The concept of integrated natural and cultural resources management, a major DOD initiative, is predicated on the simultaneous and comprehensive understanding, evaluation, inventory, and management of a broad range of natural and cultural resources. Almost all of these resources depend on, are influenced by, or are the product of the nature and occurrence of surficial soils. Consequently, these resources are affected by soil erosion *and* deposition, the kinds of phenomena that should be accurately estimated or predicted. An Integrated Natural and Cultural Resources Management Program for DOD installations must be able to accurately estimate/predict soil erosion and prescribe management alternatives to minimize erosion and mitigate impacts.

Legal requirements for managing soil and water resources on DOD installations include compliance with the Clean Water Act (CWA), Clean Air Act (CAA), Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), Superfund Amendments and Reauthorization Act (SARA), and National Environmental Policy Act (NEPA). All of these acts require DOD to determine the amount of soil erosion that may occur as a result of specific DOD activities, such as training, installation restoration, testing and development, and installation management.

Maintenance and use of training areas has a particularly strong requirement for the efficient and comprehensive application of soil erosion prediction/estimation technology. Selection of specific training areas, training dates and lengths, and allowable traffic depends on a number of considerations, not the least of which is potential soil erosion. Presently, many evaluations of the impacts of training on military lands are completed using methods that may not be state-of-the-art or the most efficient to support decisionmaking by trainers.

Goal and Objectives

The goal of this part of the project, "Soil Erosion Prediction," was to determine the best methods to *predict soil erosion by wind and water on DOD installations over applicable spatial and temporal scales as a function of both human and natural activities*. This goal contains several key elements. Both water and wind processes are important on DOD lands, particularly in semiarid and arid areas where particulates in the air can be an obscurant and an abrasive. Traditionally, soil erosion prediction efforts on DOD installations have focused on water erosion processes, with a few exceptions. Problems of scale are particularly challenging in the area of predicting soil erosion. Many methods and models of predicting soil erosion were developed for use at specific geographic scales, such as small (tens of acres) sites or drainage basins.

These tools have been inappropriately applied to larger areas, such as a training area of several tens of thousands of acres. Historically, frequently used soil erosion prediction tools have been designed for specific time intervals, most commonly an annual cycle, and are not capable of predicting or estimating erosion on an instantaneous (event), daily, or monthly period. Additionally, some human-initiated activities on military installations, such as training with armored vehicles, have received relatively little attention by researchers. The knowledge of the impact of these types of military activities on many different types of soils is limited, making the use of many existing soil erosion methods (which depend on the

input of specific soil disturbance considerations and data) difficult at best to apply to the evaluation of training alternatives.

In support of the goal stated above, a number of objectives have been identified. Although some of the objectives are beyond the scope of the effort, they are important to the eventual application of state-of-the-art technology to DOD soil and water resources management issues. These objectives and an explanation of their significance are:

1. Identify DOD requirements for soil erosion potential prediction/estimation.
2. Determine the state-of-the-art in soil erosion prediction/estimation.
3. Identify knowledge gaps in soil erosion prediction/estimation technology for use in a variety of military applications on DOD installations.
4. Recommend the use of existing methods for appropriate applications on DOD installations.
5. To the extent appropriate and feasible, fill the knowledge gaps identified in Objective 3, above.

State-of-the-art technology was also examined at the Legacy DOD/Interagency Workshop on Technologies to Address Soil Erosion on DOD Lands, held 11-15 June 1995, in San Antonio, TX. Research and applications scientists and engineers from a number of Federal and State agencies involved in developing soil erosion prediction technology were invited to present the latest products and examples of applications. Of particular relevance are the methods and models developed by the U.S. Department of Agriculture (USDA), Agricultural Research Service (ARS). The ARS has been the international leader in developing erosion prediction technology such as the Universal Soil Loss Equation (USLE), its modification (MUSLE) and revision (RUSLE), the Wind Erosion Equation (WEQ) and subsequent revision (RWEQ). Researchers at a number of ARS laboratories around the United States have recently completed a new generation of soil erosion prediction methods. These new methods, unlike their predecessors (which are empirically based), are process based. These new procedures are the Water Erosion Prediction Project (WEPP) and the Wind Erosion Prediction System (WEPS). Although WEPP and WEPS represent quantum leaps in the state-of-the-art in soil erosion prediction technology, a number of challenges remain before the full capability of these powerful tools for soil and water resources management will be realized in the DOD. In addition to the review of technologies presented at the workshop, a more complete review was subsequently conducted.

The results of the state-of-the-art review revealed that, although there are many powerful tools for application to DOD soil erosion prediction/estimation and other

soil and water resources management issues, there are some significant knowledge gaps. These gaps reflect a focus of technology on agricultural applications. Thus, there is a general lack of data on some specific military land impacts. Some of these gaps will significantly hinder the accurate prediction of soil erosion resulting from some military activities. In other cases, the gaps in soil erosion technology for DOD use may be overcome by relatively short-term computer software systems development.

This part of the document will conclude with the recommendation of specific existing methods and models for use in fulfilling DOD soil erosion prediction/ estimation requirements. These recommendations will be based on knowledge of the capability and applicability of existing tools, the kinds of applications likely to occur on DOD installations, and implementation requirements of each tool. Objective 5 stated above is beyond the scope of this project.

Development of Soil Erosion Technology

Numerical soil erosion prediction technology first became available 57 years ago with the publication of an erosion equation by R.W. Zingg (1940). Zingg's equation was the product of some of the first systematic basic research on the mechanics of wind and water erosion processes and factors that influence them. The ravages of the dust bowls of the Great Depression were still in the minds of researchers concerned about our nation's soil and water resources. Publication of Zingg's equation was followed by an extended period of research on fundamental processes and the observation of soil erosion experimental plots on a wide variety of site conditions including soils, slope, slope length, vegetation, agricultural practices, and climate (Bagnold 1941; Ellison 1947; Smith and Whitt 1947; Musgrave 1947; Smith and Wischmeier 1957; Meyer and McCune 1958; Wischmeier 1959; Moldenhauer and Wischmeier 1960).

It was not until a quarter of a century later that the next monument of soil erosion prediction was unveiled. W.H. Wischmeier and his associates in 1965 published USDA Agricultural Handbook No. 282, *Predicting Rainfall-Erosion Losses From Cropland East of the Rocky Mountains* (Wischmeier and Smith 1965). This handbook documented the USLE, an empirically based procedure to estimate annual soil erosion from croplands. The USLE was based on the premise that soil erosion due to rainfall (A) was a function of a rainfall and runoff factor (R), a soil erodibility factor (K), a slope length and steepness factor (LS), a cover and management factor (C), and the agricultural support practice factor (P). The USLE quickly became a management tool widely used by agriculturalists and others

interested in estimating soil erosion. The applicability of the USLE to a broader range of site conditions led to the use of the USLE as a general purpose erosion predictor (Wischmeier 1975). Despite the limitations of the USLE stated in the documentation of the procedure, the USLE was frequently misused, in that it was applied to site conditions for which there were no data (Wischmeier 1976).

Recognizing the need to apply an erosion prediction method to the western United States, the USLE was modified to account for more arid and mountainous regions (Williams 1975). The MUSLE added the consideration of a runoff energy factor and data from soil erosion plots west of the Rocky Mountains. Williams has continued to refine the MUSLE, with the development of MUSS (small watersheds), MUST (a theoretical version), and MUSI (user-defined version).

Not long after the introduction of the USLE, a wind erosion equation was presented by USDA scientists and engineers (Woodruff and Siddoway 1965). Based on W.S. Chepil's pioneering work of 30 years' observation of wind erosion in the Great Plains (Chepil 1945) and the physics of Bagnold (1943), the WEQ also estimated the annual soil loss on agricultural lands in tons per acre per year. The WEQ is based on the relationship between annual erosion (E) and a (wind) soil erodibility index (I), a soil ridge roughness factor (K), a climatic factor (C), a field length factor (L), and a vegetation cover factor (V). A graphical solution of the relationship was initially produced in 1965 (Woodruff and Siddoway). Like its companion for rainfall erosion, the USLE, the WEQ was warmly received and became the standard procedure for estimating soil erosion used by most Federal and State agencies.

As the USLE gained momentum world-wide, shortcomings were recognized as it was applied in new situations. Beginning in 1987, a concerted effort was initiated to make requisite improvements. The equation retained its basic structure, but each factor was revised based on new information gathered since the original version (Renard et al. 1994). The improved equation, the Revised Universal Soil Loss Equation (RUSLE), has essentially replaced its forerunner.

Increased understanding of soil erosion processes in the 1960s and 1970s lead to the production of large complex soil and water resources management models in the 1980s by ARS scientists and engineers. These models were designed to assist decisionmakers in the increasingly complex area of agricultural practices in environmental management. Almost all of these models contained a soil erosion component.

The model CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) was one of the first of this generation of tools (Knisel 1980). As a

method to predict pesticides and nutrients in surface runoff from relatively small (single field) areas, CREAMS predicts soil erosion from rainfall energy, erosivity of the soil, and a variety of other parameters. The model will predict soil erosion from daily events or storms of any time length. Soil erosion prediction is actually accomplished in CREAMS using a modified version of the USLE. CREAMS has been used in a wide variety of applications in environmental management for tracing pesticides and nutrients off-site.

ANSWERS (Areal Non-point Source Watershed Environmental Response Simulation) was developed by the ARS to model relatively small watershed soil erosion, hydrologic processes, and chemical processes (Beasley, Huggins, and Monke 1980). ANSWERS simulations were designed to determine the effects of land use and management on water quality. ANSWERS is a distributed parameter model that simulates a broad spectrum of hydrologic components, including spatially varied unsteady rainfall, interception, depressional storage, infiltration, overland flow, channel flow, tile flow, and groundwater return flow to stream channels.

A procedure to simulate the effect of soil erosion on soil productivity was formulated as the model EPIC (Erosion Productivity Impact Calculator) (Williams, Renard, and Dyke 1983). EPIC is a physically based simulation system for soil erosion, plant growth, and other related processes directly related to the soil erosion-productivity problem. EPIC simulates both water and wind erosion, the former using a modification of the USLE, and the latter using the WEQ. The EPIC model has been proven to be useful for large area estimations, such as the national Resources Conservation Assessment. Since its original development, EPIC has been continuously revised and updated for new applications and more powerful computers.

GLEAMS (Groundwater Loading Effects of Agricultural Management Systems) is a field scale simulation system based on CREAMS technology. GLEAMS was developed to evaluate the impact of agricultural practices on potential pesticide and nutrient leaching and has four components: (1) hydrology, (2) erosion and sediment yield, (3) pesticide transport, and (4) nutrients. GLEAMS could be particularly useful to military training planners in predicting the impacts of specific operations on the potential for chemical movement. Environmental managers would also find GLEAMS of substantial value in tracking the fate of chemicals and nutrients. Soil erosion in GLEAMS is accomplished using a modified version of the USLE.

ALMANAC (Agricultural Land Management Alternatives with Numerical Assessment Criteria) was adapted from EPIC as a research model. The model is designed to predict the effects of management decisions on soil and water resources

and crop production. ALMANAC was developed as a field scale model, applicable only to relatively small sites.

At a larger scale than ALMANAC, the SWRRB (Soil and Water Resources for Rural Basins) simulation system (Arnold et al. 1990), integrates surface and groundwater hydraulics models to simulate areas as large as an intermediate size watershed. The SWRRB model also borrows from CREAMS technology, particularly soil erosion.

SWAT (the Soil and Water Assessment Tool) (Arnold, Engel, and Srinivasan 1993) was developed as a large area simulator for water resources management. Comprised of three components, (1) hydrological simulation procedures, (2) a geographic information system (GIS) specifically, the Geographic Resources Analysis Support System (GRASS), and (3) a relational data base, the SWAT model is a powerful tool for managing large areas. Larger DOD installations may be appropriate for this scale of model. The soil erosion component is a modification of the USLE.

The HUMUS (Hydrologic Unit Model for the United States) is also a large area modeling procedure. HUMUS is a distributed parameter, continuous time model for use in evaluating the water resources of the United States (Srinivasan et al. 1994). It was developed for use in the Resources Conservation Act (RCA) national assessment of 1997. HUMUS uses SWAT as a basin-wide assessment procedure coupled with a GIS and a relational data base.

At the present, the ARS is developing the APEX (Agricultural Policy Environmental Extender) model for managing farms or small watersheds. The model uses EPIC methods for soil erosion to calculate daily values. The APEX model may prove to be useful in DOD in its application to relatively small agriculture-like activities on installations, such as wildlife food plots and timber harvesting programs.

Interestingly, the majority of the aforementioned models dealing with soil erosion by water use variations of the USLE. While frequently criticized (e.g., Foster 1991), the USLE remains the most widely used and accepted erosion prediction model in the world. Ease of use is one of the primary reasons for its popularity. The LS factor (slope length and steepness) has been one of the greatest controversies. The LS factor is not only extremely difficult to determine in the field, it has more impact on the resulting prediction than any of the other factors.

Recent modifications to the RUSLE greatly increase its utility and accuracy. Moore and Wilson (1992) illustrated that the LS factor in the equation is a measure of the

sediment transport capacity of overland flow. As such, they developed an LS factor analog based on the unit stream power theory an upslope contributing area. The LS analog accounts for rilling and convergence and divergence of slopes, thus producing a much more accurate erosion estimate. When applied in a geographic information system environment, changes in sediment transport capacity between adjacent cells provide a measure of erosion and deposition potential, thus extending the use of the RUSLE to sediment deposition as well as erosion. Mitasova et al. (1995, 1996) successfully integrated the approach in a geographic information system, predicting erosion and sediment deposition for complex landscapes on both military and agricultural lands.

In 1985, an ambitious initiative of the ARS was begun with the partnership of several other Federal and State agencies. The goal of the initiative was to develop completely new, process-based methods for accurate prediction of soil erosion by water and wind. The method of predicting soil erosion from water was named the Water Erosion Prediction Project (WEPP), in which wind erosion is addressed by the Wind Erosion Prediction System (WEPS). Field studies of soil erosion on a wide variety of site and field conditions were conducted by the WEPP and WEPS research teams. Both models were designed to overcome many of the shortcomings of the USLE and WEQ. The ARS focused its research on the WEPP and WEPS projects on the numerical expression of the physical, chemical, and biological *processes of soil erosion across the landscape*, not just the hill slopes and surfaces where erosive processes are active.

In August 1995, the WEPP was officially delivered by the ARS after 10 years of development and testing. A summary paper on WEPP was presented at the San Antonio workshop by Dr. John Laflen, the project leader (Appendix A). While it is hoped that WEPP will someday replace RUSLE, there are still hurdles to overcome. Soil loss estimates are often grossly inaccurate, particularly when calculated for single precipitation events (Chaves and Nearing 1991; Zhang et al. 1996). To date, only the hillslope and watershed versions are available. These versions treat the landscape as planar surfaces. Funding for the proposed grid version for use with geographical information systems has not been forthcoming. Therefore, application to complex landscapes is limited. Mitas et al. (1996), however, have applied a simplified derivation of the WEPP model in a true 3-dimensional geographical information system environment.

A technical description of the WEPS model was also delivered by ARS in August 1995. However, the model itself will not be publicly released for several years. No attempt is being made at the present time to extend the capability beyond agricultural settings. Dr. Lawrence Hagen, project leader for the development of

WEPS, presented a summary paper on WEPS at the San Antonio workshop (Appendix B).

During the past 5 years, the ARS has revised both the USLE and the WEQ. Dr. Don McCool, research engineer on the RUSLE development team, presented a paper on the subject at the San Antonio workshop, as did Dr. Bill Fryear, Project Leader for the revision of the WEQ (Appendix C to this report).

3 Sedimentation and Turbidity

Introduction

Nationally, erosion and sedimentation resulting in siltation of watercourses constitute the leading cause of impairment of rivers and streams (Harrison 1995). According to the latest available National Water Quality Inventory (1992 Report to Congress), siltation affects 45 percent of the 222,370 impaired stream miles in States reporting causes. In the eight southeastern States of the EPAs Region 4, siltation and sedimentation rank among the top four pollutants in every State. The first step toward adequate protection of rivers and streams from sediment requires recognition that several kinds of water quality standards are needed, in addition to a complement of effective best management practices (BMPs) for activities on the landscape. The four critical types of water quality criteria needed include measures of the water column, substrate, near stream/riparian zones, and biological integrity. Each type of criteria alone cannot be fully protective, but together a suite of protective measures can do the job.

Until recently, emphasis on monitoring sediment discharges was related to storage requirements and life expectancies of reservoirs. The primary motivation for collecting sediment data is now for environmental monitoring. The identification of time trends in sediment discharge may signal changes in upstream land use patterns, or may help quantify the success or failure of remedial actions. A sediment gage monitors upstream changes in the watershed, and the identification of trends at the gage justifies an examination of upstream activities to identify causes for changes in sediment discharge (Parker 1995). However, identifying trends in the sediment discharge record is difficult because of the inherent variability of the record.

The linkages from an upstream change in land use to a downstream change in sedimentation are: (1) upstream measurements of sediment discharge directly related to land use change, (2) transfer of the sediment discharge downstream (Walling 1983; Ongley 1987), and (3) the detection of the incremental change in sediment discharge at the downstream station. These linkages from upstream source to a downstream measurement site are not direct, and the controls on these linkages are variable in space and time. Different sediment discharges can result

from land-use change depending on the timing and location of the disturbance. Distance between the disturbance and gage may alter the magnitude of sediment discharge downstream.

To evaluate the magnitude of sediment discharge change needed to produce a statistically significant trend, Parker and Osterkamp (in press) found that, even in streams with low natural variability, it may be difficult to identify even a 20 percent increase in mean annual sediment discharge. They were able to detect the increase in discharge only 12 percent of the time based on sediment station data alone. This lack of sensitivity of sediment stations alone suggests that it may be necessary to couple them with assessments of upstream channel and upland erosion to identify trends. Another benefit of the upstream assessments would be to provide information on changes in sediment storage and sediment delivery.

Sediment transport is a function of five primary factors: climate, geology and soils, topography, vegetation, and land management (Renthal 1995). Near-surface geology and climate determine the type of soils that develop in the area. Soils developed in areas underlain by shale and limestone are silty and have a fine texture; soils underlain by sandstone tend to be sandy and loamy. Managers responsible for solving immediate sedimentation problems on the ground are faced with the challenge of distinguishing what is natural from what is excessive. It is important that natural sedimentation process occur for alluvial systems to function properly and to avoid creating new problems by disrupting these processes. Also, it is important to realize that solutions that locally alter sedimentation rates may cause problems up or downstream.

Evidence of Sedimentation Rate on DOD Installations

One example of sedimentation and turbidity issues on a DOD installations was described by Krupovage (1995). Tinker Air Force Base (TAFB) is a 2,023 ha, heavily urbanized, and industrialized military installation located approximately 16 km southeast of downtown Oklahoma City. It is estimated that approximately 85 percent of all Air Force installations and numerous other military reserves are comparable in size to, or smaller than, Tinker Air Force Base. In this case, construction sites are the largest contributor to sedimentation and turbidity. Sites usually range from under 1 acre to 80 acres in size. Control measures generally consist of those typical of urban construction sites, namely diversion dikes, sediment traps/basins, silt fences, hay bales, and mulching.

Shoreline erosion also is a common cause of sedimentation and turbidity. During the dry summer months, water levels may drop several feet and expose unvegetated shorelines to wave action. This leads to erosion and increases turbidity. Another process that has increased sedimentation and turbidity downstream is the channelization of many urban and suburban creeks since the 1940s, resulting in increased flow rates, incision, scour and bank sloughing. Krupevage describes a number of methods employed to deal with these increased erosion rates including the construction of storm water detention basins that also serve as sediment basins, and celled storm water treatment marshes at the inlets to several ponds to reduce downstream sedimentation and turbidity.

TAFB is home to the Texas horned lizard *(Phrynosoma cornutum),* a Federal Category 2 candidate for listing as an endangered species, which prefers sparsely vegetated areas in loose soil. This type of habitat often is perceived as counterproductive to sediment and turbidity reduction objectives, but gives an excellent example of how natural systems have evolved in concert with some levels of erosion and sedimentation. It stresses the need for an interdisciplinary team approach to erosion and sediment control involving wildlife/fisheries biologists, geotechnical engineers, hydraulic engineers, and land users.

One of the important issues that is brought to light in Krupovage's paper is that, although sedimentation and turbidity levels are regulated on TAFB, the enforcement permit does not specifically include parameters that require monitoring of turbidity. Sedimentation is monitored by the total suspended solids parameter of the permit, even though it only affects a small portion of the base. Because regulatory requirements often do not include significant sediment and turbidity parameters, obtaining funding for erosion and sediment control projects currently can be difficult for most installations. Furthermore, although relatively small eroded areas may seem insignificant as compared with erosion problems related to activities such as Army tracked vehicle training, it is important to be aware of the substantial cumulative, degradative impacts that these smaller individual sites have on water quality.

Need for Sedimentation Rate Information

The occurrence of sedimentation and turbidity can have a significant influence on public perception of how the base is managed environmentally. It becomes an indicator of overall environmental stewardship and land use management on the base. Management of soil and sediment pollution should focus on avoiding the loss

of environmentally important and sensitive areas. An understanding of the following is essential to good stewardship of soil resources:

1. *Physical Processes.* Nature maintains a very delicate balance among the following variables: the water yield from the basin, the water velocity and depth; the concentration and size of sediment particles moving with the water; and the width, depth, slope, hydraulic roughness, planform, and lateral movement of the stream channel. That balance is dynamic, not static.
2. *Impact of Sedimentation on Projects.* All projects and procedures that impact surface water resources impose some changes on the above mentioned stream variables. In some instances, these changes increase the erosive forces to such an extent that the costs for providing necessary scour protection will exceed the potential benefits of the proposed project. In other instances, the rate of sediment deposition within various water bodies and stream reaches may increase to the point where anticipated channel flood capacity or navigation depths are lost. In either instance, the resultant impacts on riparian and aquatic habitat may incur unacceptable environmental losses. The consequent costs of regularly repairing or mitigating for the undesirable changes may be too great to maintain operation of the proposed project under those specific conditions. Measuring, monitoring, and estimating the effects of projects on the water resources with respect to variables such as climate, frequency of recurrence, and proximity to sensitive areas may provide guidance on optimizing the use of the resource for both military and environmental objectives. These examples illustrate how sediment can impact the design, operation and maintenance of military installations or training programs.
3. *Impact of Project on Stream System Morphology.* The second half of the question in water resource development is: "To what extent will a project affect the behavior of the stream system?" When nature's balance is modified at one location, changes will migrate both up and down the basin. Sediment investigations need to estimate how far and how significant those changes might be.

Some effects of sediment deposition include loss of reservoir capacity, noxious weed growth in shallowed water, eutrophication, occurrence of fish kills due to temperature extremes in the shallows, low dissolved oxygen, and high turbidity.

Many of the contaminants found in storm water runoff do not dissolve well in water and accumulate to higher concentrations in sediments than in the overlying water. Contaminated sediments may, in turn, act as a source from which these contaminants can be released into the overlying waters. Benthic organisms (those organisms that live on the bottom or in the sediment) are exposed to pollutants that

accumulate in the sediments and may be affected by this exposure or may avoid the contaminated area.

Some general categories of sediment data needs include:

1. The evaluation of sediment yield with respect to different natural environmental conditions: geology, soils, climate, runoff, topography, ground cover, and size of drainage area
2. The evaluation of sediment yield with respect to different kinds of land use
3. The time distribution of sediment concentration and transport rate in streams
4. The evaluation of erosion and deposition in channel systems
5. The amount and size characteristics of sediment delivered to a body of water
6. The characteristics of sediment deposits as related to particle size and flow conditions
7. The relations between sediment chemistry, water quality, and biota.

Goals (DOD, Project)

In developing tools for estimating sedimentation rates on DOD lands, the goal is to estimate the rate of sedimentation in lakes, ponds, reservoirs, and streams on military installations over a variety of time scales and as a result of soil erosion from nonpoint sources by various processes and activities. The desired product is a protocol of procedures and methods to estimate sedimentation rates at appropriate accuracy levels in a variety of aquatic environments over different time scales. There are three objectives: (1) to measure existing transport and sedimentation rates to quantify and prioritize existing problems, (2) to monitor areas that are or may be impacted by military projects and activities, and (3) to predict sedimentation rates and turbidity levels based on best knowledge of future projects and activities to guide planning and possible mitigation and remediation.

Development of Procedures, Methods, and Techniques for Existing Technologies

Sediment sampling in the United States dates back to 1838, when the Corps of Engineers was engaged in navigation channel work on the lower Mississippi River. During the next 100 years, the need for sediment predictions related almost entirely to river navigation and estuary maintenance work. It was not until after passage of the Flood Control Acts of 1928 and 1936, when the Corps started to plan, design, and construct multiple-purpose reservoirs, that the need for sediment yield

predictions developed. Initial phases of sediment yield investigations developed sediment rating curves that were expanded in the 1950s into the popular flow-duration sediment discharge rating curve method. The emphasis on documenting sediment yield rates shifted in the 1940s to reservoir survey measurements and the relation of sediment yield to contributing drainage areas, reservoir capacities, stream density or slope, and runoff. The early work in this area was considered weak because it related sediment yield to only a few of the many contributing factors.

Next, during the early 1950s, efforts were concentrated on expanding Musgrave's definition of quantitative factors for small land units to the drainage increments of large river control projects. These evaluations attempted, without much success, to relate factors on a regional or annual basis in lieu of local or seasonal definitions. During this same period, sediment sampling and reservoir survey measurement techniques were enhanced. Long-term basin runoff characteristics were also identified to improve confidence in the sediment rating curve-flow duration method. However, by the late 1950s, project planning had shifted to smaller drainage areas. The definition of local drainage controls and urban runoff assumed greater importance and the "big dam" criteria for yield predictions was no longer vogue. This change required a downward extrapolation toward the upper limits of Soil Conservation Service criteria. To meet this need, plans were implemented to document urban runoff characteristics and correlation techniques concentrated on qualifying the adequacy of short term records. As the environmental issues of the late 1960s developed their impetus, design criteria and needs mushroomed into the broad fields of water quality control, biological reproduction, eutrophication acceleration, and most recently, wastewater management. Adequate methods for predicting the impact of sediment yield on the food chain and habitat of aquatic species and on wastewater disposal have not been developed yet.

In the early days of fluvial-sediment investigations, each investigator or agency concerned with sediment developed methods and equipment individually as needed. In 1939, representatives of the Corps of Engineers, Flood Control Coordinating Committee of the Department of Agriculture, the Geological Survey, the Bureau of Reclamation, the Bureau of Indian Affairs of the Department of the Interior, and the Tennessee Valley Authority formed an Interdepartmental Committee with the expressed purpose of standardizing sediment data collection equipment, methods, and analytical techniques. In 1946 the committee became known as the Subcommittee on Sedimentation of the Federal Interagency River Basin Committee. The Subcommittee reorganized the project in 1956 to its present structure as the Federal Interagency Sedimentation Project (FISP). Its present location is at the

Waterways Experiment Station of the Army Corps of Engineers in Vicksburg Mississippi (Edwards and Glysson 1988).

While the real need is to forecast future conditions, available data such as land use, rainfall, and runoff are historical in nature and useful for hindcasting. Hindcasting is also a required technique for "confirming" that procedures for forecasting will be valid for the proposed study area. In forecasting, all physical parameters must be estimated. Finally, two different levels of forecasts are needed: (1) the long-term average to provide results for project life and maintenance; and (2) for single events. Specific requirements vary from one type of project to another.

The primary developmental changes in technologies for measurement and sampling are due to the digitization and computerization of formerly analog manual tasks and the advent of relatively inexpensive tools for positioning from satellite GPS systems. Many tasks that formerly required constant human monitoring can now be measured, recorded and stored in data loggers for up to months at a time and then directly downloaded into software programs that reduce the data and produce graphical output in a few easy steps. This greatly reduces the time and expense in the long run of measuring and monitoring many physical phenomena such as water surface levels, temperature, velocities, and for on-site measurements of depth, position, and velocity. Skill and knowledge of the hydrodynamics, sediment transport, and electronics are all required for proper installation and use of the equipment and interpretation of the data, but the so called "leg work" has been greatly reduced.

Review of State-of-the Art

While the laboratories of the USDA are pursuing the state of the art in overland flow, erosion, and sediment transport as mentioned in earlier sections of this report, the USGS and Army Corps of Engineers are the leaders in research, technology, and methodology development, and training for in-stream flow and sediment transport work. The USGS is charged with monitoring the nation's waterways for flow and sediment characteristics and is the primary source for data records on rivers and information and training on how to sample sediments and the flow characteristics of rivers in conjunction with the FISP. The Corps of Engineers is responsible for research into design and modeling aspects of rivers, reservoirs, and waterways.

The U.S. Army Corps of Engineers has developed a series of one- and two-dimensional modeling programs to address various aspects of river and reservoir flow and sediment transport. One-dimensional models are less complex than the

two-dimensional models and are used to model larger areas over longer time periods. They are more effective in modeling long-term changes with steady flow conditions rather than say, a single storm event, but are currently being developed for unsteady flow. Two-dimensional models require more complexity in input information and set-up and are used to model smaller areas and shorter time periods including events. The 2-D models can model unsteady flow conditions as well as the steady flow.

The first generation of one-dimensional models analyzed the flow and sediment aspects separately. HEC-2 is a one-dimensional model of the hydraulic parameters of the water body including water surface elevations and velocities. HEC-2 is based on a backwater type calculation and was used to model the flow alone or as the input for sediment modeling programs such as HEC-6, which models scour and deposition in rivers and reservoirs. In July 1995, a second generation program called HEC-RAS, the River Analysis System, was released; it combines the hydraulic and sediment transport models for a full network of natural and constructed channels into one package. The system contains three one-dimensional hydraulic analysis components for: (1) steady flow water surface profile computations, (2) unsteady flow simulation, and (3) movable boundary sediment transport computations. A key element is that all three components use a common geometric data representation and common geometric and hydraulic computation routines. In addition to the three hydraulic analysis components, the system contains several hydraulic design features that can be invoked once the basic water surface profiles are computed. The current version of HEC-RAS only supports Steady Flow water surface profile calculations. New features and capabilities will be added in future releases.

Daily sediment stations are manpower intensive because of the large amount of field sampling and laboratory work required. Many agencies continue to look for surrogate measures of sediment concentration to lower costs and provide continuous sediment record. Turbidimeters have been used with some success in rivers that carry primarily fine-grained suspended material (Walling 1977).

The Federal Interagency Sedimentation Committee has also examined several methods to measure suspended-sediment concentration continuously. One example is a vibrating U-shaped tube through which river water is pumped (Skinner and Beverage 1986). The vibrational period of the tube is a function of the water density, which, in turn, is related to sediment concentration. Work also continues on a plummet gage, which continuously records water density changes as a function of the buoyant forces on a glass bulb submerged in river water (Skinner and Szalona 1991).

Available Technologies

Data Sources

USGS Daily Value, Peak Value, Precipitation CD-ROM Format.

- *scale*: River reaches between gaging stations all over the United States.
- *accuracy*: Noted in summary and report sections for each gaging station.
- *requirements*: IBM PC, CD-Rom Drive
- *cost*: Not applicable (N/A)
- *time*: short. Menu driven, easy to use and learn.
- *contact*: Earthinfo. Inc. 5541 Central Avenue, Boulder CO. 80301 (303-938-1788) Fax 303-938-8183

Models

The Modular Modeling System (MMS). An integrated system of computer software that has been developed to provide a framework needed to support the development, testing, and evaluation of hydrologic-process algorithms and to facilitate the integration of user-selected sets of algorithms into an operational hydrologic model. MMS uses a master library that contains compatible modules for simulating water, energy, and biogeochemical processes. Initial modules in the library were derived from the USGS Precipitation Runoff Modeling System (PRMS)—a watershed model in which parameters are distributed by partitioning the drainage basin into units assumed homogeneous in their hydrologic response (HRUs) (Leavesley et al. 1983). Additional modules have been included using selected process algorithms from the National Weather Service River Forecast System (NWSRFS) model and TOPMODEL (Beven and Kirkby 1979). New modules for channel transport of solutes and sediment have also been developed and included. Additional modules will be added to the library as research and operational applications expand MMS use. A GIS interface is available for the analysis and manipulation of spatial data in model parameter estimation using digital data bases for a variety of characteristics including elevation, soils, vegetation, and geology.

The MMS framework has been developed for use in the X-windows environment on a UNIX-based workstation. A graphical user interface provides an interactive environment for users to access system features, apply selected options, and graphically display results.

Models linked together can provide powerful tools for environmental assessment. The output from one model becomes the input of another, allowing predictions of quantities such as bed-sediment transport from alterations in drainage basin land

use or changes in components of the water balance of the basin (Parker, Klingeman, and McLean 1982).

Hydraulic Design Package for Channels (SAM). SAM provides the computational capability to evaluate erosion, entrainment, transportation, and deposition in alluvial streams. Channel stability can be evaluated and used to determine the cost of maintaining a constructed project. SAM's major application has been as a tool for reconnaissance studies to highlight whether or not an in-depth study is necessary.

- *scale*: river reach
- *accuracy*: N/A
- *requirements*: Main frame or PC computers, a person with knowledge of sediment transport and hydraulics trained to use SAM. SAM has been taught in Corps Prospect classes over the past 4 years, as well as at on-site training in districts
- *cost*: Typically, students in courses pay ~$1500.00 and receive the package as part of training
- *time*: varies.

HEC-6 Scour and Deposition in Rivers and Reservoirs. HEC-6 is a one-dimensional numerical model of river mechanics that computes scour and deposition by simulating the interaction between the hydraulics of the flow and the rate of sediment transport. This model was designed to be used for the analysis of long-term river and reservoir behavior rather than the response of stream systems to short-term, single event floods. HEC-6 does not simulate bank erosion or lateral channel migration. Features of HEC-6 include: capability to analyze networks of streams, channel dredging, various levee and encroachment alternatives, both bed and suspended load, incorporates interactions of flow hydraulics, sediment transport, channel roughness and related changes in boundary geometry. The transport, deposition, and erosion of silts and clays may also be calculated. Effects of the creation and removal of an armor layer are also simulated.

A supplementary document titled *Application of Methods and Models for Prediction of Land Surface Erosion and Yield*, Training Document No. 36 (March 1995) was prepared by the Hydrologic Engineering Center as a guide for developing watershed sediment yield data for HEC-6. This document draws heavily on the state of the art techniques described in the report sections on Soil Erosion Potential and Status. It provides a description of the methodologies used and the practical theory behind them. Especially helpful is the chapter that presents a detailed example of how to prepare the data and apply procedures to estimate the average annual and single

event sediment yields for a watershed investigation. It also discusses methods for estimating the inflow load

- *scale*: river, reservoir

- *accuracy*: one dimensional models will give the overall sediment erosion or deposition in a reach by distributing the effect evenly across the area so there is no provision for simulating the development of meanders or specifying a lateral distribution of sediment load across a cross section. Because it uses a sequence of steady flows to represent discharge hydrographs, conditions of very unsteady flow would not be accommodated. However, this serves as a guide for defining reaches so that important areas are not "averaged out" in the modeling process. Typically these numerical models are more accurate, less costly, and quicker than an actual physical model of the river. The accuracy is dependent, in part, on the quality of the input data collected from the field. Three restrictions on the description of the network system within which sediment transport can be calculated are:
  1. Sediment transport in tributaries is not possible.
  2. Flow around islands; i.e., closed loops, cannot be directly accommodated.
  3. Only one junction or local inflow point is allowed between any two cross sections.

- *requirements*:
  - Field Data: topographic cross-sections with stations and elevations, including the left overbank, main channel, right overbank and their corresponding reach lengths, n values, moveable bed portion of cross section, depth of movable sediment material, effective and ineffective flow areas, in flowing sediment load in tons/day for both bed and suspended load expressed as a log-log function of water discharge in cfs vs. sediment load in tons/day by grain size class, grain sizes, unit weight of deposits, fall velocity.
  - Hydrologic Data: water discharges, temperatures, downstream water surface elevations and flow duration given as a computational hydrograph.

- *cost*: $10,000- 65,000 based on complexity of study.

- *time*: varies

References/training.

Sedimentation Investigations of Rivers and Reservoirs. This manual was designed to guide the engineer in planning, conducting, and reporting the results of a sedimentation study. Help is provided in selecting appropriate methods and levels of detail for studies typically encountered in river and reservoir engineering. The format is: point out potential problems, suggest acceptable approaches for their analysis, and identify checkpoints and pitfalls. This manual does not present detailed procedures for solving sediment equations, but a Sedimentation Glossary is provided to aid in reading the references.

EPA Guidance Specifying Management Measures for Sources of Nonpoint Pollution In Coastal Waters. This document contains guidance specifying management measures for sources of nonpoint pollution in coastal waters and information on rivers and reservoirs as well. This "management measures" guidance addresses five source categories of nonpoint pollution: agriculture, silviculture, urban, marinas, and hydro modification. Many of the sections have information applicable to military installations such as the sections on stream side management, road construction and reconstruction, and road management. The document directs the user to appropriate sources of information on techniques and practices. A suite of management measures is provided for each source category. In addition, a chapter is included that provides other tools for protection, restoration, and construction of wetlands, riparian areas, and vegetated treatment systems.

Training: G-0912, "Sediment Data-Collection Techniques," 18 October 1991, Dallas Childers, Class Coordinator, USGS-CVO Vancouver, WA. This course includes classroom lectures, laboratory, and field training and is a comprehensive treatment of the concepts of sediment sampling.

Field Methods for Measurement of Fluvial Sediment. U.S. Geological Survey Open-File Report 86-531. This report describes equipment and procedures for collection and measurement of fluvial sediment. The complexity of the hydrologic and physical environments make it essential for those responsible for the collection of sediment data to be aware of basic concepts involved in the processes of erosion, transport, deposition of sediment, and equipment, and procedures necessary to representatively sample and measure sediment data. The report has two major sections. The "Sediment-Sampling Equipment" section encompasses discussions of characteristics and limitations of various models of depth- and point-integrating samplers, single-stage samplers, and support equipment. The "Sediment-Sampling Techniques" section includes discussions of representative sampling criteria,

characteristics of sampling sites, equipment selection relative to the sampling conditions and needs, depth- and point-integrating techniques, surface and dip sampling, determination of transit rates, sampling programs and related data, cold-weather sampling, bed-material and bedload sampling, measuring total sediment discharge, and reservoir sedimentation rates.

The complex phenomena of fluvial sedimentation cause the required measurements and related analyses of sediment data to be relatively expensive in comparison with other kinds of hydrologic data. Accordingly, the purpose of the manual is to help standardize and improve efficiency in the techniques used to obtain sediment data so that the quantity and quality of the data can be maximized. Representative samples may be analyzed for sediment concentration, particle-size distribution, or, if collected with the proper type sampler, any other dissolved, suspended, or total water-quality constituent. Therefore, the equipment and methods described in this report should also be used to collect a representative sample for water-quality analysis. Procedures for the processing of surface-water and bed-material samples for water-quality analysis may be found in the U.S. Geological Survey Techniques of Water Resources Investigations *Method for Collection of Surface-Water and Bed-Material Samples for Chemical Analysis*.

Bed Material Grain Size Samples: Wolcott & Church, Wolman.

Field Data Collection Methods.

Sediment Transport Method. This is a very common and indirect method used to measure load in and load out of reservoirs. The sediment load carried by all major streams entering the reservoir and the outflow load there from are determined. (International Organization for Standardization 1982).

- *scale*: reservoir, i.e., pond, lake, tank, basin or other space either natural in its origin or created in whole or in part (by building of engineering structures), which is used for storage, regulation and control of water.

- *accuracy*: depends on the selection of the sampling and measuring sites and the sampling equipment, method, and programs used.

- *requirements*: The suspended sediment sampling program must be designed to produce sufficient data for the reliable determination of mean daily suspended sediment discharge as must the bed load determination. If bed load transport is to be computed through the use of empirical formulae, an adequate program must be developed to measure or sample the required

parameters, for example slope, depth of flow, bed material particle size distribution, etc. A knowledge of bed features is an advantage. The relevant standards for equipment and practice for all measurements must be adhered to. The ISO has standards for suspended sediment, bed material sampling and stream-flow measurements.

Measure Sediment Accumulation or Capacity Survey. A direct measurement technique that can be carried out at pre-selected time intervals. This technique not only provides data from which the total volume of sediment accumulation can be calculated, but also provides information on the spatial distribution.

Sub-Bottom Profiler (Pingers and Boomers). Standard subbottom profiling sonars require higher energies for deeper penetration and shorter pulses for better resolution. Pulse length determines the resolution length and beam width affects lateral resolution. Primarily used for determining changes in substrate layers; technology could be used to distinguish pre-impoundment from post impoundment sediments to get a total deposition depth. Many advances have been made since then and the manufacturers would be able to supply the latest information and pricing (Heinz 1977).

Side-Scan Sonar. An acoustic submerged search tool can be used to identify subsurface sediments and sediment surface disturbances. Width, length, and height of bottom objects can be measured. Sediment and faunal boundaries can be located and mapped on the basis of their acoustical response.

4 Tools To Support Erosion and Sedimentation Prediction

Introduction

Soil erosion is the second greatest concern at military facilities according to a recent review of problems associated with the management of military lands. The DOD needs to be able to describe quantitatively the current status of its soil resources and the magnitude of erosion at each installation. If the Army is to meet its challenge to objectively predict impacts and effects of training on its lands, it must develop a standard model to clearly consider soils, vegetation, and climate, and other environmental factors against standard Army training categories. An important element to any such model is the ability to clearly identify and quantify the current soil status throughout a given installation at various spatial scales and accuracy levels.

This chapter summarizes the current tools that can identify and quantify the current soil status at installations, including maps of elevation, soil types, vegetative cover and other cover features; geographic information systems; and climatic and land-cover analysis models. These maps vary in accuracy and scale, in information presented, and in the techniques used to create them.

The goal is to define standards for accuracy levels and identify standard procedures for producing maps where none currently exist. Standards for digital representations of mapping information will also help provide consistent input to models that can use current information to predict future soil erosion potential.

Development of Modern Technology in Soil Status Evaluation and Mapping

An obvious tool for identifying existing soil and erosion status is the use of maps that show features such as elevation, soil type, hydrography, and vegetative cover. These can be used to provide information about slope and aspect and the current status of erosion. Combined with climatic data and input on training impacts, they may also be used with models to predict future erosion potential.

Maps may be available on paper or in digitized format. Digitized maps provide the most flexible tools as they enable quantitative analysis via GISs. They may be combined with digitized information about other factors such as training impacts, and they may provide input to analysis models.

Perhaps the most useful maps are those for elevation, soil type, and vegetative cover. Digital elevation models (DEMs) provide information on slope and aspect, generate gully maps, and help quantify soil loss. Other features that may be of interest in identifying current soil status include: hydrography, transportation, pipelines and transmission lines, manmade features, and boundaries.

The subsections below summarize many of the currently available maps for elevation, soil, land cover, and other features that may be helpful in identifying current soil status. In some instances technologies and applications are also discussed. Information presented includes:

1. Elevation or terrain data maps:
   - USGS DEMs
   - Defense Mapping Agency (DMA) Digital Terrain Elevation Data (DTED)
   - IFSAR

2. Soil maps:
   - NRCS Soil Survey Geographic Data Base (SSURGO)
   - NRCS State Soil Geographic Data Base (STATSGO)
   - NRCS National Soil Geographic Data Base (NATSGO)
   - considerations for creating new soil surveys and maps

3. Land cover:
   - USGS Land Use and Land Cover (LULC) maps
   - Texas National Guard case study of land cover analysis using remote sensing techniques

4. Other features:
   - Defense Mapping Agency (DMA) Interim Terrain Data (ITD)
   - Digital Line Graphs (DLG)
   - USGS data available through the Internet.

Table 1. Sources of terrain data.

Source	Characteristics	Plan Accuracy	HL Accuracy
USGS DEMs	Available for most of the United Stated in digital form	15-30 m	7-15 m
USGS 7.5-ft quad	Readily available hard copy format	12 m	½ CI (5 ft)
IFSAR	All time and weather	5-10 m	3 m
NAPP DEMs	In 5-year cycles	2 m	3 m
NGS Control	Sparse (20-40 points/quad); may not be visible from the air	2 cm	5 cm
GPS Survey	Useful for photo-photogrammatic control	2 cm	5 cm

Elevation Maps

Table 1 summarizes several sources of terrain data or digital elevation models (DEMs), several of which are discussed in the following section.

U.S. Geological Survey (USGS) Digital Elevation Model (DEM)

USGS DEM data is a uniform matrix of terrain elevation values and is available in 7.5-minute, 15-minute (Alaska only), and 1-degree units.

DEM data in 7.5-minute units correspond to the USGS 7.5-minute topographic quadrangle map series and consist of regular arrays of elevations arranged horizontally on the Universal Transverse Mercator (UTM) coordinate system of either the North American Datum of 1927 (NAD 27) or NAD 83. These data are stored as profiles with 30-m spacing along and between each profile.

DEM data in 15-minute units correspond to the USGS 15-minute topographic quadrangle map series in Alaska and consist of regular arrays of elevations arranged horizontally to the coordinate system of NAD 27. The spacing between elevations along profiles is 2 arc seconds of latitude by 3 arc seconds of longitude.

DEM data in 1-degree units are produced by the Defense Mapping Agency in 1- by 1-degree units that correspond to the east or west half of USGS 1- by 2-degree topographic quadrangle map series (1:250,000 scale). These data consist of a regular array of elevations arranged horizontally using the coordinate system of either the World Geodetic System 1972 (WGS 72) Datum or WGS 84 Datum. Spacing of the elevations along and between each profile is 3 arc seconds. The only exception is DEM data in Alaska, where the spacing varies depending on the

latitude. Latitudes between 50 and 70 degrees N have spacings at 6 arc seconds, and latitudes greater than 70 degrees N have spacings at 9 arc seconds.

The accuracy of DEM data depends on the source and resolution of the data samples. The accuracy of the 7.5-minute DEM data is derived by comparing linear interpolated elevations in the DEM with corresponding map location elevations and by computing the statistical standard deviation or root-mean-square error (RMSE). The RMSE is used to describe the DEM accuracy. The vertical accuracy of 7.5-minute DEMs is 15 m or better. The 15-minute DEM accuracy is one-half of a contour interval of the 15-minute topographic quadrangle map or better. The 1-degree DEM data have an absolute accuracy of 140 m horizontally and 30 m vertically.

Defense Mapping Agency (DMA) Digital Terrain Elevation Data (DTED)

DTED is a uniform matrix of terrain elevation values and is available as DTED Level I or Level II. DTED Level I has a post spacing of 3 arc seconds (approximately 100 m, depending on latitude). North of 50 degrees latitude, the post spacing in the longitude direction increases. The information content is approximately equivalent to the contour information represented on a 1:250,000 scale map. Exploitation at larger scales (smaller areas) must consider each individual cell's accuracy evaluation.

DTED Level II is a uniform matrix of terrain elevation values with a post spacing of 1 arc second (approximately 30 m, depending on latitude). North of 50 spacing in the longitude direction increases. The information content is approximately equivalent to the contour information represented on a 1:50,000 scale map. Exploitation at larger scales must consider each individual cell's accuracy evaluation.

DTED Level I and Level II use a geographic coordinate reference system of the World Geodetic System (WGS 84). The file size is a 1-degree X 1-degree (approximately 108 km X 108 km) geographic cell identified by its southwest corner coordinates.

Accuracy statements are individually calculated for every product and are provided in the Accuracy Header Record. The accuracy objectives for both DTED Level I and Level II are ±50 m at 90 percent circular error (CE) for absolute horizontal and ±30 m at 90 percent linear error (LE) for absolute vertical.

IFSAR

IFSAR (interferometric synthetic aperture radar) is a remote sensing technology that produces terrain data. The basic accuracy goals of the IFSAR System are 3 m vertical and horizontal at 90 percent confidence for a collection rate of 100 km^2 per minute and 1-m vertical and horizontal at 90 percent confidence for some (presently unspecified) lower collection rate. The 3-m accuracy must be met over distances up to 50 km at the 100 km^2 rate, and the 1-m accuracy must be met over distances up to 20 km. The accuracy statement specifies relative or point-to-point accuracy.

The downside to compiling DEMs from remotely sensed imagery using traditional stereo photogrammetry is that fairly rigorous (and expensive) photogrammetric instrumentation is a necessary hardware investment.

High-resolution elevation models have many potential applications in soil-loss management. Resource managers can:

- use high-resolution elevation models (smaller post spacing interval than the DMA DTED or USGS DEMs) to quantify soil loss
- use high-resolution elevation models to examine mitigation and restoration alternatives
- use high-resolution elevation models to provide better volumetric estimates, better slope estimates, and better "run" estimates
- use high-resolution elevation models to generate exact gully maps for mitigation and restoration as well as for characterization and monitoring.

Gully maps can be integrated with high-resolution imagery to examine the degree of tonal differences. Some degree of tonal difference can be expected in highly erosive areas, and can result in different digital values on the imagery. This spectral component can be useful for general identification of an erosive area, but is not particularly helpful for detailed mapping. High spatial definition in an image is useful for mapping. The resolution of an image pixel should not be larger than half the width of any gullies that are to be measured and mapped. Sub-meter imagery pixels are, consequently, the determining factor when assessing a sensors ability to successfully map an erosive area.

Soil Maps

The development of a soil map involves two processes: an actual soil survey of the area and the mapping or digitizing of that information. The spatial scale or

accuracy of a soil map is dependent on both the detail of the soil survey data and the resolution used in the mapping process. Commonly used scales are described below. The same may be true of a maps temporal accuracy.

Soil mapping data produced by the U.S. Department of Agriculture Natural Resources Conservation Service (NRCS) already exists for many areas of the country. One of the primary missions of the NRCS is soil surveys and mapping. The agency maintains archives of geographic databases at the National Cartography and GIS Center in Fort Worth, TX.

The NRCS maintains soil geographic databases on three scales. Each of these contain spatial data (the geographic information) along with attribute data linked to the state soil survey database. With these digital databases, users can store, retrieve, analyze, and display soil data in a highly efficient manner, as well as integrate the data with other spatially referenced resource and demographic data in a GIS.

The three soil geographic databases are the Soil Survey Geographic Data Base (SSURGO), the State Soil Geographic Data Base (STATSGO), and the National Soil Geographic Data Base (NATSGO). Data such as particle size distribution, bulk density, available water capacity, soil reaction, salinity, and organic matter is included for each major layer of the soil profile. Also included are data on flooding, water table, bedrock, subsidence characteristics of the soil, and interpretations for erosion potential, septic tank limitations, engineering, building and recreation development, and cropland, woodland, wildlife habitat, and rangeland management.

SSURGO, the most detailed level of information, is created from detailed soil survey maps at a scale of 1:12,000, 1:15,840, 1:20,000, or 1:24,000, which is typical of the mapping done for county-level soil surveys. It is used primarily for farm and ranch conservation planning; range and timber management; and county, township, and watershed resource planning and management. Using the soil attributes, this data also serves as an excellent source to review site development proposals and land use potential, to make land use assessments, and to identify potential wetland areas. Using national mapping standards, soil maps in the SSURGO database are made by field methods, by using observations along traverses, and by determining map unit composition by field transects. Aerial photographs are interpreted and used as the field map base.

STATSGO contains digital data at a uniform scale of 1:250,000, which can be combined with USGS base maps of the same scale and can be displayed to represent an entire State. It is used primarily for river basin, State, and multicounty resource

planning, management, and monitoring. Soil maps for STATSGO were made by generalizing the detailed soil survey maps. Where more detailed maps are not available, data on geology, topography, vegetation, and climate were assembled, together with satellite images. Soils of analogous areas are studied, and a determination of classification and extent of the soils is made.

NATSGO is the most general database at a scale of 1:7,500,000. It is used primarily for national, regional, and multi-State resource appraisal, planning, and monitoring. The boundaries of the major land resource area (MLRA) and land resource regions were used to form the NATSGO database.

If soil surveys or maps are not currently available for a given facility, they must be created. This can be done through working arrangements with NRCS and other agencies. In fact, NRCS encourages cooperative agreements with agencies and institutions for digitizing soil maps.

The first step is a soil survey. Time required to complete the field mapping depends on factors such as the size of the area, the number of personnel assigned to the project, the mapping intensity required, and the availability and quality of any existing mapping. Characterization of new soil series requires additional work in the field and in the laboratory. Because soil surveys do not usually address soil erosion factors, additional time or personnel is required to include that information. Soil erosion surveys may include information such as location, type, and intensity of existing soil erosion activities and identification of potential erosion sites.

The second step is the actual mapping or digitizing of the survey data. Priorities for digitizing existing surveys are generally based on local interest and need and, in many cases, on local funding. Preference to digitizing is given first to ongoing soil surveys, second to surveys on orthophoto or USGS 7.5 minute controlled base, third to modern soil surveys on an uncontrolled base, and forth to surveys that need updating. The NRCS encourages working agreements with other agencies to speed such projects. If the NRCS contributes resources to such projects, they must meet NRCS technical specifications for the soil survey geographic database and the State soil geographic database.

NRCS estimates of cost of soil survey mapping ranges from 50 cents to $10 per acre, depending on total acreage, complexity, scale of mapping, or complications such as the presence of unexploded ordinance (UXO).

Land Use and Land Cover

An important factor in quantifying the current status on Army lands is the existing soil cover type and quantity. This information may be added to existing maps and digitized geographic databases to permit further analysis along with soil data and models that can predict erosion potential.

USGS Land Use and Land Cover (LULC)

The USGS has compiled a base series of land use and land cover maps. Land use can be defined as human activity related to the land, and land cover as vegetation, water, natural surface, and construction on the land surface. The maps are produced at scales desirable for river basin planning, barrier island change analyses, river quality assessments, environmental impact statement preparation, and urban development studies.

The land use and land cover maps are compiled using a classification system with nine general categories and 37 subcategories. The general categories are: (1) urban or built-up land, (2) agricultural land, (3) rangeland, (4) forest land, (5) water, (6) wetland, (7) barren land, (8) tundra, and (9) perennial snow and ice.

The smallest area mapped for urban sites, bodies of water, mines, quarries, gravel pits, and some agricultural uses was 10 acres. A minimum mapping unit of 40 acres was used for all other categories. Most of the USGS land use and land cover and associated maps were compiled on planimetric base maps at a scale of 1:250,000, but some were produced at a scale of 1:100,000.

Aerial photographs and other remotely sensed data served as the primary sources for compiling land use and land cover maps. Secondary sources included earlier land use maps and maps prepared by field survey methods. The USGS land use and land cover maps were checked in the field when necessary.

Land Cover Analysis with Remote Sensing Techniques.

A recent effort by the Texas National Guard illustrates how various tools may be combined to provide land cover analysis. The Texas National Guard recently analyzed land cover at eight Guard training sites using a combination of terrestrial biological surveys, color infrared (CIR) aerial photography, thematic mapping (TM) satellite imagery, a global positioning system (GPS), and a GIS. This analysis also used the Nature Conservancys national community classification system, which

may be used to provide consistency in plant community identification over large areas (Wolfe et al. 1995).

Data may be gathered through traditional ground surveys or through remote sensing techniques. This study used color infrared (CIR) aerial photography and thematic mapping (TM) satellite imagery combined with field surveys and ground truthing. Information was entered into an Arc/Info GIS.

It was found that CIR aerial photography provided more detailed delineations than TM. TM is limited to 30-m resolution, whereas CIR enabled delineations to the community or species level. However, delineations performed with TM were much faster than those for CIR and, at larger scales, the cost of CIR becomes prohibitive compared to TM, leading to the suggestion to use TM for initial delineations and CIR for later detail work.

Other findings included:

1. County surveys are a good starting point, but may be biased to range species.
2. Historical aerial photography is valuable in revealing changes in the landscape.
3. Historical records and literature are valuable in developing presettlement views of the landscape.

Other Feature Data

DMA Interim Terrain Data (ITD)

ITD is a standard DMA digital terrain analysis product designed to support systems fielded in the 1990s, until Tactical Terrain Data (TTD) is available in volume. ITD data sets are composed of attributed information equivalent to the content of the hard copy 1:50,000 scale Tactical Terrain Analysis Data Bases (TTADBs). ITD consists of six segregated thematic feature files, including surface materials (soils), surface configuration (slope), surface drainage, vegetation, transportation, and obstacles. The data uses a geographic coordinate reference system (latitude/longitude) of the World Geodetic System (WGS 84), or a local datum where no conversion to WGS 84 exists. The vertical datum used is Mean Sea Level.

The accuracy for ITD is the same as 1:50,000 scale Topographic Line Map (for TTADB source ITD) and 1:250,000 scale Joint Operations Graphic (for PTADB source ITD).

USGS Digital Line Graphs (DLG)

Digital line graph (DLG) data are digital representations of cartographic information. DLG s of map features are converted to digital form from maps and related sources. USGS DLG data are classified as large, intermediate, and small scale.

Large-scale DLG data are available in nine categories:

1. Hypsography, including contours and supplementary spot elevations
2. Hydrography, including flowing water, standing water, and wetlands
3. Vegetative surface cover, including woods, scrub, orchards, vineyards, and vegetative features associated with wetlands
4. Non-vegetative features, including lava, sand, and gravel
5. Boundaries, including State, county, city, and other national and State lands such as forests and parks
6. Survey control and markers, including horizontal and vertical positions
7. Transportation, including roads and trails, railroads, pipelines, and transmission lines
8. Manmade features, including cultural features not collected in other major data categories such as buildings
9. The Public Land Survey System, including township, range, and section line information.

Large-scale DLG data are derived from USGS 1:20,000-, 1:24,000-, and 1:25,000-scale 7.5-minute topographic quadrangle maps. If 7.5 minute maps are not available, sources are used in the following order of preference: (1) advance manuscripts for 7.5-minute maps, (2) published 15-minute quadrangles at 1:62,500 scale (1:63,360) scale for Alaska), and (3) archival compilation materials for 15-minute quadrangles such as 1:48,000-scale compilations.

Presently, intermediate-scale DLG s are sold in five categories: (1) Public Land Survey System; (2) boundaries; (3) transportation; (4) hydrography; and (5) hypsography. Intermediate-scale DLG data are derived from USGS 1:100,000- scale 30- by 60- minute quadrangle maps, If these maps are not available, Bureau of Land Management planimetric maps at a scale of 1:100,000 are used, followed by archival compilation materials.

Small-scale DLG data are sold in three categories: (1) boundaries, including political and administrative boundaries; (2) transportation, including roads and trails, railroads, and cultural features (airports and the Alaska pipeline); and (3) hydrography, including streams and water bodies, and hypsography (Continental

Divide only). Small-scale DLG data are derived from such maps as the USGS 1:2,000,000-scale sectional maps of the National Atlas of the United States of America. Alaska hydrography data were collected at 1:1,000,000 scale from Landsat images from 1979. Other categories of data were revised from 1979-80 sources.

DLG data do not carry quantified accuracy statements. However, the data files are checked and validated before they are released for distribution for file fidelity and completeness, attribute accuracy, and topological fidelity. For large- and intermediate-scale DLG s, additional data validation such as edge matching and quality control flagging is performed.

U.S. GeoData Available Through the Internet

The USGS offers select U.S. GeoData databases through the Internet. They can be retrieved using anonymous File Transfer Protocol (FTP) or World Wide Web. The databases and their directory paths are:

- 1:2,000,000-scale DLG:
  /pub/data/DLG/2M
- 1:100,000-scale DLG, hydrography and transportation layers only:
  /pub/data/DLG/100K
- 1:100,000-scale land use and land cover data:
  /pub/data/LULC/100K
- 1:250,000-scale land use and land cover data:
  /pub/data/LULC/250K
- 1-degree digital elevation model data:
  /pub/data/DEM/250K

Decision Tree for Selection of Methods, Requirements, etc.)

The Texas National Guard case study presented above combines several tools to provide a consistent means of land cover analysis:

- traditional soil surveys
- remote sensing techniques: color infrared (CIR) aerial photography and thematic mapping (TM) satellite imagery
- global positioning system (GPS)
- geographic information system (GIS)
- a standard vegetation classification system (the Nature Conservancys National Community Classification System)

The following scenario shows one possible process to produce current land views that can provide input to the USLE models for soil loss prediction:

1. Use ortho-rectified images automatically generated from high-resolution DEMs such as generated from IFSAR
2. Generate perspective views, landform patterns, relief maps automatically from high-resolution DEMs such as generated from IFSAR
3. Consider how climate combines with geomorphic characteristics to fashion the land surface and its soils. Provide climatic models that consider topographic influences when calculating climate spreading values over the area of interest. Climate characteristics of interest include parameters such as precipitation amount and rate, and wind speed and direction
4. Use topographically influenced climatic models to calculate the R factor in the USLE
5. Use IFSAR derived high resolution DEMs to calculate the L and S factors in the USLE.

Orthophoto products, which are a means of producing maps, are also helpful if archival photos are available. Photos of a region from different times can provide information about soil and vegetative changes.

State-of-the-Art Tools for Assessing Soil Erosion/Sedimentation

Remote Sensing

The geology, soils, and land forms of many places on the Earth have been mapped with the aid of remotely sensed data. Data sources used include black and white, true color, and color infrared aerial photography; multispectral satellite imagery (e.g., Landsat and SPOT); radar imagery (synthetic aperture radar, SAR and interferometric SAR, IFSAR); thermal infrared imagery (TIMS); AVHRR; and multispectral aerial data (e.g., AVIRIS). Geologic, soils and landform mapping is based on recognizing areas of similar structure and/or similar tone.

Because aerial photography has been used for a long time by many countries and agencies, aerial photos provide archival data that can be useful in change detection studies to delineate soil erosion areas. Change detection can be done by direct measurement on photos or by using image processing if the photos are digitized (film emulsion densities changed to digital form) and rectified (any distortion in the photo is removed by forcing features on the photo to coincide with their depiction on a topographic map) to produce orthophotos. Aerial photographs can also be used in conjunction with satellite imagery to provide additional scene information. Drainage patterns, land use, and vegetation communities identified on photography are indicative of particular soil types. Additionally, stream channel shape and channel deposition characteristics tell something about the soils in an area.

For additional information, see the section on Orthophoto products later in this chapter.

Global Positioning Systems

Topographic systems that incorporate the Global Positioning System (GPS) have been proven to obtain accurate vertical (height) measurements of 1 to 3 cm. In the past, these accuracies involved long observation times using the static Differential GPS (DGPS) method. Recent advances in DGPS technologies have provided similar vertical accuracies in only a few seconds of observation time. Not only can these accuracies be obtained while sitting static on a particular point, but they can also be obtained while in motion.

GPS technology also provides horizontal position data that can be used to quickly and accurately define point and polygon features on the ground by conducting field location surveys. GPS surveys are used to create a database of positions associated to land use patterns, site facilities, soil type or any other ground feature that has definable physical attributes (such as the factors that influence soil loss in an area). Horizontal positions on selected features in the field within this database can serve as an external check for remote sensing and thematic mapping data. Using differential GPS techniques (DGPS) and real-time surveying (with radio communication between rover unit and a reference receiver at a known position), a single GPS surveyor can collect position data using a self-contained backpack unit containing a receiver, antennas, radio link, and batteries.

Commercial GPS systems (which are available from various manufacturers) include the full suite of GPS hardware needed to conduct field surveys either by establishing a reference station over a known control point to generate position corrections (transmitted by radio to the remote field GPS unit). Alternatively, the code

differential corrections are available in certain areas from the USCG radio beacon system, or can be obtained by subscription to a commercial DGPS correction service. The data collector units allows the GPS field operator to navigate to a specific predetermined location (that might be scaled off a map) and record the position of the feature of interest with an accuracy between 1 and 3 cm using On-the-Fly (OTF) or to meter-level accuracy using code differential corrections. Features located with GPS in this manner can also be described in the field with text notes or customized feature codes entered into hand-held data collector in the form of an attribute file that can be exported to a GIS.

Geographic Information Systems

A GIS is a tool that enables display and analysis of digitized geographic information. Thus, GIS is really an analysis tool rather than a mapping tool. It is important here because such systems allow digital information on different features or from different sources to be analyzed together, and because it enables easy quantification of information. For example, a GIS could show geographically and give total acreage of soils of a given type found on a given slope range. Geographically linked data on training sites and impacts may also be entered into GIS databases for further analysis.

Commonly used GIS systems include GRASS, developed by the U.S. Army Construction Engineering Laboratories (USACERL), and ARC/INFO, a commercial GIS from Environmental Systems Research, Inc. (ESRI)*. Most GIS systems today can export and import data formats of other systems. A consideration, however, is whether raster or vector data is most appropriate to represent and analyze the desired information. For example, soil types are commonly stored as raster (or pixel-oriented data), whereas elevation, roads, and hydrology information is more easily presented as vector (point, line, and polygon) data.

Orthophoto Products

Orthophotos are images produced from aerial photographs. Positional errors caused by camera angle or the displacement of terrain features because of elevation are removed. These distortion-free images are formatted into orthophoto products in either black-and-white or natural color versions. Three orthophoto products are described below: orthophotomaps, orthophotoquads, and digital orthophotos.

* Environmental Systems Research, Inc., 390 New York Street, Redlands, CA 92373.

Orthophotomaps. Orthophotomaps are published topographic maps, at scales of 1:24,000 or 1:25,000, prepared by superimposing the names, symbols, patterns, and topographic features of standard 7.5- minute maps on natural color orthophoto bases. These maps are principally prepared to show subtle topographic and vegetative details in areas of low relief, such as coastal marshes and flats, with the topography represented by spot elevations and one or two contour lines. Orthophoto-map coverage is mainly along the Gulf and Atlantic coasts, from Texas to Maryland, and in some flat areas in scattered States.

Orthophotoquad. Orthophotoquads are orthophotos that are produced in standard quadrangle formats with no contours and only a few location names and symbols. They were initially produced as preliminary 7.5-minute quadrangles. Because they show a wealth of planimetric details and land use and land cover information that is not shown on conventional line maps, they make excellent supplements to the published maps. Orthophotoquads have also been produced for other Federal agencies, for use as base maps for thematic data such as land use classifications.

Orthophotoquads and orthophotomaps are prepared to meet National Map Accuracy Standards. Various accuracy tests performed verified that 90 percent of the well-defined points were within 40 ft* of their true position, which is the horizontal accuracy standard for 1:24,000-scale maps.

Digital Orthophotos. A digital orthophoto is a digital image of an aerial photograph with displacements caused by the cameral angle and the terrain removed. The following items are required to produce a digital orthophoto:

1. Ground control points that can be identified from photographs
2. Cameral calibration and orientation parameters
3. A digital elevation model (DEM)
4. A digital image.

The digital image is rectified to an orthographic projection by processing each image pixel through photogrammetric equations derived from the first three items above on a high- speed image processing system. The finished product is a spatially accurate image with planimetric features represented in their true geographic positions.

Both a digital orthophoto and a conventional orthophoto are produced using the principles of differential rectification. When a conventional orthophoto is produced,

* 1 ft = 0.305 m.

the image is scanned in small strips or patches, with rectification occurring at the center of the strip or patch. In a digital orthophoto, each pixel is corrected for relief displacement and camera orientation, which results in a more accurate image. Unlike conventional orthophotos, a digital orthophoto can be manipulated in any GIS that accepts raster images. Also, when a digital orthophoto is used as a foundation, other layers of data can be overlaid and manipulated in the GIS. This capability allow users of GIS data unlimited flexibility.

The primary digital orthophoto is a 1-m ground resolution quarter-quadrangle image (3.75- by 3.75-minutes) at a scale of 1:12,000, cast on the UTM projection on the North American Datum of 1983 (NAD 83). A 7.5-minute quadrangle can be produced by merging four 3.75-minute quarter-quadrangle digital orthophotos. Primary and secondary datum transformation constants are included in the header record and allow users to spatially reference other digital data with the digital orthophoto.

The accuracy and quality of USGS digital orthophotos must meet National Map Accuracy Standards at 1:12,000 scale for quarter- quadrangles and 1:24,000 scale for quadrangles. Accuracy and quality are dependent on these factors:

1. Photographs that meet National Aerial Photography Program (NAPP) standards, exposed at a flying height of 20,000 ft above round, and with a 152.4-mm (6-in.) focal-length camera
2. A DEM with the same area coverage as the digital orthophoto that is equal to or better than a level 1 DEM with a root-mean-square error of no greater than 7 m
3. A highly accurate image scanning process that employs a scanning resolution between 7.5 and 32 microns (a 1:40,000-scale image scanned at 25 microns equates to a pixel ground resolution of 1 m)
4. Photo-identifiable image and coordinates of ground control positions acquired from ground surveys or aerotriangulation.

5 Botanical Composition

Introduction

In natural systems, biotic and abiotic processes do not operate independently. Therefore, the process of soil erosion in a natural system cannot be fully understood and accurately modeled without considering the geophysical and biological mechanisms that control soil erosion. Likewise, plant succession cannot be fully understood without considering the geophysical and biological mechanisms that control the process. Botanical composition is a good indicator of the health and successional stage of a natural system. Changes in composition caused by natural or man-made disturbance, when considered from an ecological perspective, can influence soil erosion status and potential and can be useful in early detection of soil erosion problems.

The purpose of this chapter is to evaluate the current and emerging technologies to determine botanical composition and introduce the importance of integrating geophysical and biological knowledge from an ecological perspective. The result will be to define what DOD must do to move toward an ecosystem management program.

Vegetation Factors Affecting Soil Erosion

Vegetation, in general, is an indicator of rangeland condition. Perennial species are especially important indicators of rangeland condition (Thurow 1985). These species stabilize the soil during dry periods; their decline is usually associated with increased soil erosion potential (Walker 1994). The growth form of vegetation and the position of a plant species on the successional scale are important factors in determining the infiltration rate (Woodward 1943, Dee, Box, and Robertson 1966). In general, infiltration rates are highest under trees and shrubs followed in decreasing order by bunchgrass, sodgrass, and bare ground. The reverse relationship is generally true for sediment production (Thurow 1985). However, Duley and Domingo (1949), McGinty et al. (1979), Meeuwig (1970) and Blackburn (1975) report that standing crop and organic cover are important factors, regardless of species, in determining infiltration and sedimentation. Therefore, although each

factor alone (species, standing crop, or cover) may exhibit a correlation with infiltration or sedimentation, the interactive effects of the three factors together provide a better predictor of infiltration and sedimentation.

Infiltration rate and sediment production are inversely related and sediment production is strongly dependent on infiltration rate. Infiltration rate combined with storm intensity determine the amount of runoff and the energy associated with runoff water seems to be the overwhelming factor determining sediment yield (Thurow 1985).

There is little quantitative information in the literature comparing training use to sediment yield (Thurow, Warren, and Carlson 1993); however, extensive work has been done regarding livestock grazing as a major rangeland use. Conclusions from this research indicate that comparisons of different types of grazing use with infiltration and sediment yield is of limited value because the real issue is not grazing itself, but rather how grazing alters the soil and vegetation components that affect the hydrologic relationships (Thurow 1985). The same paradigm will be true for training use (Thurow, Warren, and Carlson 1993). Past research has treated vegetation and soil parameters as independent variables. This simplistic approach is of limited value when the goal is to develop a predictive capability to devise better management approaches. Most of the parameters are interrelated to some degree and understanding the interrelationships is critical if future research and resulting management strategies are going to advance beyond current status. It is also necessary for vegetation and soils data to be collected over time in a consistent and periodic manner that will enable insight into how changes occur over time (Thurow 1985).

Need for Botanical Composition and Cover Information

During the soil erosion workshop, the issue of "why focus on botanical composition" as compared to vegetative cover was posed to the group. Based on past research and experience, the major concern is with vegetative cover in general. This is true, especially in terms of the propensity of a land area to erode as a function of existing plant cover. However, the term "botanical composition" is more complete than "vegetative cover"; changes in botanical composition and coverage can be used to detect stress, thus serving as an indicator of areas with potential erosion problems. Thus, the state of the vegetation can be used as an indicator or surrogate for erosion potential and status. In addition, there is interest in determining which types of vegetation can be used to predict soil status, and which might be better for controlling erosion, with regard to both native and exotic species (Smith 1995). The

desired product is a protocol of procedures and methods to characterize and measure in appropriate terms and qualities the composition of botanical species and communities as they influence and/or indicate soil erosion potential, soil erosion status, sedimentation rate, and turbidity levels.

Regarding a related, but higher level of organization, concepts related to equilibrium versus nonequilibrium models of vegetation and ecosystem development were discussed. These models are important only in relation to how we view soil erosion on military facilities. The DOD will continue to conduct training at its facilities. Hence, it must focus on understanding erosion as a process (the geophysical and biological interrelationships) and on the consequences of training activities for erosion potential and status.

Goals (DOD, Project)

The priority ecosystem components identified by the DOD, from a policy perspective are water quality, soil stability, native biological diversity, and the integrity of cultural resources. The goal of this project is to define what the DOD and the Services must do to etablish an ecosystem management program because they possess and use Federal land for many types of training and testing missions. The DOD must know what resources it has and the condition of those resources. The DOD is committed to determine through interagency identification and consensus, what existing technologies can be adapted to DOD needs to meet Federal land management policy.

The specific objectives of the workshop were to: (1) determine the best technologies available, in use in DOD and other agencies for estimating soil erosion potential, status, and sedimentation rates and turbidity levels, and for characterizing/measuring botanical composition; and (2) obtain a preliminary "working level" consensus on the best technologies acceptable to both DOD and land management and regulatory agencies.

Development of Procedures, Methods, and Techniques

Remote Monitoring

Remote sensing applications for vegetation studies are numerous and are of particular interest to natural resource managers. In general, remote sensing is an important data source that can be integrated with other spatial data in a GIS and

used as a tool by natural resource managers to assess vegetation parameters of interest over large geographic regions. More specifically, remote sensing has been used to map botanical composition (Kremer and Runnig 1993; Smith et al. 1994), percent vegetative cover (Tucker 1979; Zhuang, Shapiro, and Bagley 1993), biomass (Anderson, Hanson, and Haas 1993; Kauth et al. 1978), and other ecological parameters of interest to installation resource managers. The level of detail and accuracy of information pertaining to vegetation that can be derived from remotely sensed imagery varies greatly and depends on sensor type, spatial scale, ecological setting, and the availability and reliability of other ancillary data, including field surveys.

The use of traditional satellite imagery such as Thematic Mapper (TM) and SPOT for mapping vegetation has been widely applied in different ecological settings. Typically, areas of known vegetation type or plant community are either located in the field or visually delineated on a digital image. Reflectance values of pixels or data elements within these boundaries of known vegetation type are then used to statistically analyze the reflectance values of the remaining unknown pixels in the image, and based on their respective reflectance values in different wavelengths recorded by the sensor, individual pixels are then assigned to discrete categories in a process know as supervised classification. However, vegetation maps derived from this process using only space borne imagery are general at best, and may not provide the level of detail desired by resource managers. This process gives the capability to distinguish between forested and grassland cover types, or deciduous versus coniferous forest, for example, but identifying individual plant species or even communities is difficult (Lauver and Whistler 1993).

Limitations are due in part to the limited spatial and spectral resolution of satellite sensors, and also due to the fact that different vegetation types may exhibit similar reflectance characteristics, which therefore makes it difficult to differentiate them spectrally. Ancillary spatial data such as soils, elevation, slope, and aspect are often combined with imagery to help distinguish between vegetation types and plant communities that are spectrally similar in a process know as post- classification sorting (Dejong 1994; Franklin 1994). Traditional manual air photo interpretation remains the best technique for vegetation and plant community mapping. Acquisition of photography is relatively low cost in comparison to satellite imagery costs. However, data collected by photographic methods contains limited spectral information and does not lend itself well to automated spectral classification algorithms. As a result, manual interpretation of aerial photography requires skilled personnel and is labor intensive, thereby increasing the overall cost of the process.

However, air photo interpretation does provide the capability to map plant communities, habitats, or even individual species. Airborne multispectral and hyper spectral sensors have improved our capability to delineate vegetation types because of increased spatial and spectral resolution. However, these methods have been costly, and as a result, have only been tested in controlled experiments in the research and development community. In the near future, as this technology is tested and becomes more cost efficient, these sensors should greatly enhance the ability to map vegetation types and communities at a higher level of detail. Remotely sensed imagery is also commonly used to measure and monitor vegetation characteristics such as percent vegetative cover, biomass, and condition or vigor, all of which are useful to installation trainers and resource managers (Tucker 1979).

Airborne and space borne sensors record reflectance across a broad spectrum of wavelengths. Within each portion of the spectrum, different properties of vegetation control the amount of electromagnetic energy that is absorbed, transmitted, or reflected. In general, healthy vegetation has been characterized by low reflectance in the visible wavelengths and high reflectance in the near infrared wavelengths. Low reflectance in the visible wavelengths is due primarily to high absorption of pigments such as chlorophyll in the leaves. Low reflectance in the blue and red bands corresponds to the two chlorophyll absorption bands. However, there is a slight increase in reflectivity in the visible green portion of the spectrum, which explains why healthy vegetation typically appears green to the human eye.

In the context of natural resource management, an inverse relationship exists between the spectral response in the visible region, particularly in the red wavelengths, and biomass production of a plant. In the near infrared region of the spectrum, cell structure dominates the spectral response. Unlike the visible regions, there is no strong absorption in these wavelengths and relatively high reflectance and scattering. Therefore, high reflectance in the near infrared wavelengths is directly proportional to plant biomass. Other portions of the electromagnetic spectrum are also analyzed to assess vegetation amount and condition, but most vegetation applications are focused primarily on reflectance in the red and near infrared portions of the spectrum. Combinations or ratios of these two wavelengths are used to derive vegetation indexes.

Several vegetation indexes have been developed to reduce multispectral scanner data observed by satellites to a single number or index, for the purpose of qualitatively and quantitatively assessing vegetation conditions. Due to the vast number of indexes that have been developed and exploited, the description of each is beyond the scope of this literature review. However, almost all vegetation indexes are calculated to assess parameters such as percent vegetative cover or bare ground,

above ground biomass, green leaf area index, absorbed photosynthetically active radiation, and canopy moisture content. Of these parameters, percent cover and biomass are likely of greatest interest and use to trainers and resource managers.

Typically, a parameter such as percent cover or biomass is measured in the field using an appropriate sampling scheme. Depending on the parameter actually being measured, the appropriate vegetation index is then calculated for all pixels in the image that correspond to the areas sampled on the ground. Vegetation index values are then correlated with measures of percent cover or biomass, for example, which are measured in the field. If a strong correlation exists, the vegetation index is calculated for all remaining pixels in the image, and based on the regression formula used to establish a correlation between the imagery and field data, an estimate of percent cover or biomass is extrapolated across the entire image (Tucker 1979; Zhuang, Shapiro, and Bagley 1993).

Vegetation index techniques have been applied with varying success, depending on ecological setting. In arid environments, vegetation is sometimes too sparse and soil background dominates (Heilman and Boyd 1986; Pickup 1993; Satterwhite 1984). In forested areas, vegetation indexes are often correlated with canopy characteristics, but estimation of understory characteristics is difficult because of canopy cover (Franklin 1994; Law, and Waring 1994). Typically, vegetation indexes are best for predicting percent cover and biomass in areas of minimal canopy cover with at least moderate ground cover (Zhuang, Shapiro, and Bagley 1993). However, different variations of vegetation indexes have been developed that minimize the limitations associated with different ecological regions.

The spectral and spatial limitations of traditional sensors such as SPOT and TM are also a limiting factor in the ability to estimate percent cover and biomass using vegetation indexes. As airborne multispectral sensors become affordable and are tested in the field, they should also improve estimates of percent cover and biomass. Collection of airborne imagery can be controlled by resource managers and scheduled to collect information during seasons when there is greatest contrast between certain vegetation types (Chavez and Mackinnon 1994; Price, Pyke, and Mendez 1992). In addition, imagery can be flown pre- and post- exercise to do change detection on a very small temporal scale. Collection of satellite imagery is dictated by sensor orbit, and therefore data is not always available for optimal time periods.

Regardless of sensor type, classification method, or vegetation index of interest, ground truth data will always be necessary. Field surveys are used as input into the supervised classification process, and perhaps more importantly, are used to

assess the reliability and accuracy of classification results and vegetative cover and condition estimates. Accuracy assessment is critical if information derived from remotely sensed imagery is to be used as input into resource management decisions.

High accuracy, high density DEMs have traditionally been successfully generated using stereo photogrammetry. However it is expected that the emerging technology of interferometric SAR (IFSAR) will change this. IFSAR systems are capable of rapidly generating high accuracy DEM data and orthorectified SAR images over large geographic areas.

In this age of hyper spectral imaging systems (many narrow band passes as compared to a few broad bands), knowledge about the spectrum (reflectance over a wavelength range) of a material allows you to select the band pass on the scanners so that some desired material is most contrasted with other materials. For example, to detect vegetation using Landsat TM, a ratio of bands 4/3 would yield high values for pixels that were predominantly vegetation (about 5) and low values for sand (about 1.5). The spectra of many common materials have already been measured and are available in spectral libraries, which provide a good reference for determining the spectral characteristics of materials at different wavelengths. If the spectral reflectance has not been measured, it can be measured in the laboratory or in the field with a spectrophotometer.

GPS technology also provides horizontal position data that can be used to quickly and accurately define point and polygon features on the ground by conducting field location surveys. Precise logging and retrieval of geopositions for vegetation surveys and vegetation change detection can be greatly enhanced by the centimeter-level accuracy available with DGPS.

Field Techniques

There are many sound methods available to measure or characterize botanical composition at ground level (Bonham 1989; Goodall 1952 and 1953; Heady, Gibbens, and Powell 1959; Mueller-Dumbois and Ellenberg 1974). The method chosen should be dependent on the specific objectives for acquiring the information and the temporal and spatial scales of interest (small site, watershed, landscape, regional, etc.). The Army has the lead to develop policy and an ecosystem management program to move away from single species management and site specific management of resources.

The Army's Land Condition Trend Analysis (LCTA) program is a multiple resource inventory and monitoring technique that employs the line-intercept method to

estimate and characterize botanical composition and vegetation cover (Tazik et al. 1992). The LCTA procedure was designed to include random sampling on permanent plots that are stratified by soil and land cover type. The method facilitates landscape level analysis of natural resources including botanical composition. The LCTA program and methodologies have been pronounced valid by a panel of natural resource experts (U.S. Army Corps of Engineers 1989).

Summary

In summary, different remote sensing and field sampling techniques are best for different applications. Detailed mapping of individual species or plant communities requires field sampling or air photo interpretation, or some combination of both. However, manual interpretation is labor-intensive and costly. Such air photo surveys are typically flown on a 5- to 10-year repeat cycle. More general vegetation mapping and estimates of cover can be derived from more frequent satellite imagery. Data acquisition is costly, but automated processing techniques continue to improve. On a landscape scale, some combination of remote sensing techniques, field surveys, and geographic information from other sources are required to provide resource managers with useful and cost effective information about botanical composition, biomass, cover and condition.

6 State-of-the-Art in Modeling Soil Erosion

Much has been accomplished in the over half a century of focused research on the development of accurate methods for soil erosion prediction. However, much remains to be completed in the difficult and complex problem of numerical simulation and expression of the many interrelated processes of soil erosion. The development of both empirical and mechanistic models of soil erosion, transport, and deposition have traditionally focused on single elements of the problem, such as "sheet and rill" erosion on hillslopes and streambank erosion of stream channels. The WEPP watershed model and some of the soil and water resources models such as ANSWERS, EPIC, SWRRB, and SWAT developed by the ARS are significant steps toward the simultaneous (or step-wise) prediction of the movement of soil particles through all elements of the landscape. There remains, however, a need for additional research in the *coupling* of the processes and products (soil and water) of all of the subsystems of the soil and water transport system.

Figure 1 diagrams the coupling of existing and future numerical models of soil erosion. The top diagram differentiates the various components (sheet and rill; gully, channel) of the soil erosion system and the products they produce (runoff, sediment, organics, chemicals). These products become the input of the next subsystem of the chain. In the case of erosion by water (top diagram), the development of an accurate model of soil erosion by gullies is a significant technology gap in the current state-of-the-art. On areas where gullies occur on DOD installations, there are no methods that will predict all of the soil loss of the area.

Presently, the most practical and widely accepted technology for modeling soil erosion by water is the RUSLE, particularly when used with currently available new-generation tools and modifications that extend its applicability to large-scale complex landscapes. The WEPP model holds tremendous promise within the next few years assuming the problems of data intensity, inaccuracies, and lack of 3-dimensional integration can be overcome with GISs. As a general rule, no wind erosion prediction models are currently available that meet DOD requirements. It is hoped that the WEPS model will fill that void.

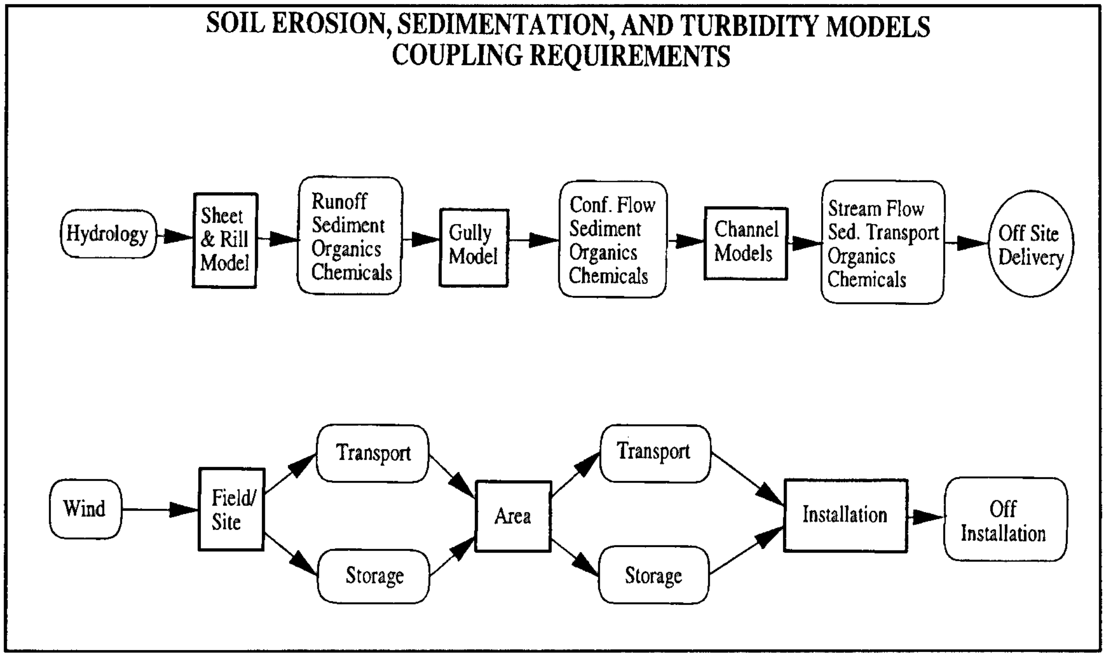

Figure 1. Coupling diagram.

Sedimentation and Turbidity

Sedimentation rates, like the ecosystems they are a part of, have features that tend to complicate management. First, sedimentation rates are dynamic. They are always in a gradual state of flux but occasionally undergo dramatic change due to fire, wind, flood, or some other agent. Second, people are part of the ecosystem. The demands that people place on the system are also dynamic, changing, and competing with even less predictability than natural physical forces. Therefore the objectives of any project to manage sedimentation rates must be specific. One example might include limiting suspended sediment in the stream to an acceptable concentration. Activities and objectives must be matched to local conditions. There is no single appropriate set of objectives or techniques that will provide a solution to every sedimentation problem.

Sedimentation and turbidity are normal processes that vary in space and time. This variance makes the process of planning accurate data collection and the subsequent analysis a function of the planners knowledge of the specific aquatic system. It is important to know that the effects of averaging and other forms of reducing data can affect the perceived status of the system. Geological, hydrological, and biological processes function on a wide range of time scales. What is insignificant geomorphologically may be critical biologically. For example, monthly or yearly averages of turbidity and suspended sediment data may not show a statistically significant increase when large pulses of sediment are averaged over a long time. However, the impacts on living organisms with biological cycles on much shorter time scales may be very important. For instance, siltation of riverbed

gravels immediately after spawning may suffocate the eggs even if the sediments are transported out within a month. Although there may be no net annual deposition, the timing of deposition becomes a limiting factor in the life cycle of a species. Conversely, very small incremental increases that may be adjusted for in the short term may degrade the system over long periods of time. Knowledge of these relationships should guide sampling and monitoring strategies for assessing actual impacts of changes in sedimentation rates and turbidity levels.

There are two fundamental steps to assessing and/or predicting sedimentation rates at any scale: (1) measuring, and (2) modeling. All of the models require some level of field data measurements for input parameters, calibration, and verification. The spatial scale of such measurements is typically a point that may truly represent that point but typically becomes an assumed representative average of values between measurement points. For instance, a one-dimensional model will require a cross sectionally averaged discharge for computing water surface elevations and transport properties. The USGS provides such stage/discharge relationships at crossection stations on many rivers in the United States.

To do this, they must complete a thorough survey of the channel topography and water surface elevations and calculate the average velocity at multiple sections across the cross section by taking velocity measurements at one or two depths in each section. On a shallow stream, the current practice is to use hand-held mechanical propeller type or electromagnetic velocity meters. This procedure must be repeated at different flows for the full range of flows to establish a rating curve from which continuous measurements of stage can be used to find the discharge from the curve. The rating curves tend to change with time depending on the stability of the channel geometry, and so must be verified periodically. For three-dimensional models, a more complete data set on the velocity magnitude and direction in vertical and lateral profiles are required as input conditions. A tool that has proved useful for rapid measurement of these velocity fields is an acoustic DOPPLER device. However, these devices do not effectively measure the velocity very near the bed or surface due to physical limitations.

The accuracy of newer acoustic techniques is still being evaluated. Tests on the Mississippi River have shown differences between the electromagnetic readings and those of the acoustic sensors. It is not yet known what these differences mean in terms of accuracy.

7 Conclusions and Recommendations

Conclusions

This study concludes that DOD must accomplish the following critical steps to effectively and efficiently implement an ecosystem-based management program:

1. Work must be begun to resolve the problem of numerical simulation and expression of the many interrelated processes of soil erosion, especially research into the coupling of the processes and products (soil and water) of all the subsystems of the soil and water transport system.

2. Requirements for evaluating sedimentation and turbidity include:

   - determine/negotiate standards (both air and water)
   - address potential violations of law
   - relate standards to impacts
   - initiate/carry out monitoring to ensure standards of compliance
   - establish integrity of aquatic ecosystems
   - establish and protect riparian corridors
   - determine the portion of stream sediment yield that arises from DOD properties
   - develop management plans for severe storm events
   - evaluate sorting and redistribution of soil particles as related to vegetative cover
   - determine eolian contributions to water quality
   - evaluate stresses on hydrologic systems
   - assess damage to aircraft due to airborne particles
   - determine air quality impacts during training maneuvers—must assess air quality adjacent to training areas during maneuvers including off-site impacts
   - control airborne sediment to decrease maintenance of land and range facilities, by reducing unnecessary impacts to the system
   - control turbidity and sedimentation as required by the threatened and endangered species plan.

3. Cost factors that contribute to the cost of a sedimentation rate study include:

   - equipment purchasing or renting
   - field measurements
   - laboratory analysis of samples and data
   - model complexity
   - pay hours required to accomplish each of the previous steps.

4. In addition to the need for additional research into the coupling process and for understanding sedimentation concerns, a number of other shortfalls in current knowledge and/or technology need to be addressed, including:

   a. Complete description of biological communities and habitat maintenance as related to the impacts of sediment-associated contaminants in streams

   b. Full information about where the sediment is deposited and how long it is stored in an area before being transported downstream

   c. Development of water quality standards to protect rivers and streams from "clean sediment" that keeps pace with standards and monitoring with toxicity testing; development of a comprehensive suite of protective water quality standards addressing sedimentation needs

   d. Development of defensible water column criteria for suspended sediment/turbidity, in-stream habitat criteria for substrate changes, and scientific input on the critical functions and structure of riparian areas and their sizes and configurations for aquatic ecosystem protection

   e. Development of a sound strategy based on specific goals and objectives for integrated vegetation management plans that are oriented to meet the training and testing needs

   f. Quantification of cause and effect relationships of vegetation responses to training

   g. Delineation of the interrelationships between vegetation and soil components and how training use alters the hydrologic processes

   h. Development of definitive guidelines for restoring and integrating the use of natural processes e.g., fire, biological pest control

i. Determination of the best combination of field data and various forms of remotely sensed data to meet goals and objectives of vegetation management plans;

j. As outlined in a sound strategy based on specific goals and objectives, coordination of a balance among site specific, training area level, watershed level, landscape level and regional level, scales of data

k. Data collection over time in a consistent and periodic manner that enables insight into how changes or vegetation dynamics occur over time

l. Evaluation of the contributions of sediment and turbidity from DOD installations to the larger ecosystem

m. Evaluation of the role of sedimentation and turbidity in management of threatened and endangered species

n. Development of additional methods to analyze the connection between uplands and downstream integrated systems

o. Development of methods to measure and track sediment movement, and to distinctly qualify and quantify what is being measured

p. Establish access to integrated data bases, particularly for issues of botanical composition

q. Development or refinement of applicable predictive simulation models of the interrelationships between vegetation and soil components and how training use alters the hydrologic processes

r. Expansion of interagency cooperation and consensus.

Recommendations

In general, this study recommends that the DOD:

- move beyond compliance to best management practices (BMPs)
- adopt management practices that will allow DOD installations to operate (train) and remain in compliance (CWA, CAA)
- partner with State and other agencies on developing and refining methods

- strive to exceed achieving only compliance in its stewardship activities
- pursue opportunities to stabilize upland soils with native vegetation
- show that BMPs can be used to reduce sedimentation and turbidity and potentially enhance the carrying capacity of the land resource for military use. (Through monitoring of sedimentation and turbidity, DOD can sell its projects.)

Soil Erosion Prediction

It is recommended that DOD continue to use the RUSLE model and incorporate the new generation tools that extend its applicability to both erosion and sediment modeling in complex terrain. Simultaneously, DOD should actively pursue and support ongoing efforts to improve the WEPP model as a potential process-based replacement for the RUSLE. In the case of both models, there should be close coordination with LCTA and carrying capacity efforts to ensure that the necessary field data are collected in a cost effective manner, and that necessary spatial databases are fully populated.

As there are currently no wind erosion models shown to be applicable to military lands, it is recommended that the DOD actively participate in the development and validation of the new generation WEPS model to ensure that it is capable of estimating soil erosion by wind on military training and testing lands.

Tools to Support Erosion/Sediment Modeling

The status of eroded lands on DOD will usually be obtained from, or depicted on, a variety of map-related products. The scale and accuracy of a map are important considerations for any type of activity, including determining soil erosion status. The accuracy of a digitized map is dependent both on the techniques used for producing the map and on the digitizing process, that determines the degree of information per pixel.

Many maps are already available from a variety of sources. Various techniques are employed to produce these maps, and the resulting maps vary greatly in scale and applicability.

Where appropriate maps do not currently exist, that information must first be gathered at an appropriate scale (via ground surveys, remote sensing, GPS, or some combination of technologies) and then processed and digitized into a useful format at appropriate level of accuracy. If new maps must be produced, items to be considered include:

- desired information type
- detail level of information required (scale and accuracy)
- existence of base maps that may be built on
- technology that will be used to analyze the information (raster or vector GIS, analytical models, etc.)
- best available technologies to acquire the necessary information
- time and cost requirements to use those techniques
- specific characteristics of site being mapped (unexploded ordinance, etc.).

The only practical approach to erosion and sediment modeling in large areas of complex topography is requires the use of topographic information systems.

Sedimentation and Turbidity

Critical areas on DOD lands where the sedimentation rate is an issue and secondly where a given treatment is most beneficial need to be identified as soon as possible. This may a two stage process consisting of: (1) measurement programs in areas already identified as critical, using information from soil erosion mapping to identify other unrecognized impacted areas to begin measurements, and (2) data collection for baseline and monitoring studies. Considerations to be addressed in these studies include:

- Sediment particles may serve as carriers for toxic substances
- Need for point source controls and materials/techniques having potential for least impact
- Addition of proactive management plans to address potential problems before they become compliance issues
- Disturbance of natural waterways by wheel and track vehicles.
- Restore waterways to reduce sediment transport downstream
- Avoid sediment deposition into wetlands
- Dust problems negatively affect equipment and troops.
- Develop biological filtering systems to reduce sediment deposition into streams (including constructed wetlands, riparian habitat)
- Nonpoint source water quality problems are caused by: soil disturbances, loss of vegetation (bare soil), disturbances of riparian areas, loss of in stream habitat, and disturbances on steep slopes.
- Sediment and chemical contaminant deposition in off-site public reservoirs, especially including water supply reservoirs.
- Public perception of sedimentation problems—sedimentation (due to wind or water) is essentially an off-site problem, and is therefore a major issue

influencing the perceptions of casual observers relative to DOD stewardship of soil and water resources.

- Sedimentation impacts on infrastructure maintenance—must assess how sedimentation impacts the maintenance of infrastructure (e.g. bridges, culverts, equipment).
- Bases as conduits for upstream/upwind sediments -- DOD bases may be conduits for sediments from upstream/upwind sources and may be blamed for impacts.

Botanical Composition

Five issues should be considered when using remote sensing for botanical composition:

1. Improve the recognition accuracy in image classification by employing multidimensional image classification, i.e., combine multispectral and ancillary information into the classification algorithm. Including topographic data, such as elevation and aspect information, into the classification algorithm has been demonstrated to improve the accuracy in classifying land cover from Landsat MSS images by 27 percent. Inclusion of the topographic information made it possible for the classifier to differentiate between species with similar spectral characteristics but different habitats. This information can provide an increased confidence in the soil type and a better understanding of an areas' soil erosion potential.

2. Provide spectral reflectance information that the analyst can use to characterize and classify land cover

3. Exploit new sensors more capable of measuring vegetation species composition and biomass; this capability will be helpful in estimating the potential for increased soil loss. Change detection pairs may illustrate the time frame in which vegetation cover is no longer adequate to prevent gullying and rilling.

4. The C-factor in the Universal Soil Loss Equation (USLE) reflects the relative protection afforded to the soil surface by various kinds and amounts of vegetation and other protective soil coverings. The C-factor is typically measured in the field through regular monitoring of transects. However, in the absence of remotely sensed imagery, C-factor values measured in the field were simply averaged over large geographic areas that are heterogeneous in terms of cover. Remotely sensed imagery can be used to calculate vegetation index values for each pixel or data element in the image based on reflectance

in the red and near-infrared wavelengths. Regression techniques are used to correlate percent vegetative cover measured in the field with vegetation index values of corresponding pixels in the satellite image. The resulting regression equation is used to spatially extrapolate the C-factor across the entire image, thus creating a C-factor data layer in the USLE model.

5. Recommended sensors are; DMSV, videography, B&W or color photography, SPOT, Landsat™.

6. The Army's LCTA component of the ITAM program has been implemented on over 50 major training and testing installations across the United States and Germany. Many of these installations have 5 to 7 years of LCTA data to draw from. LCTA has been found a valid multiple resource characterization procedure, and perhaps more thorough than procedures used by other land management agencies. The line intercept method of estimating botanical composition is scientifically valid and based on defined objectives and scales of interest. The accuracy of the method has been rated on a qualitative basis as being equal or better than other agency methods and statistical analyses of some LCTA databases have been completed (Price et al. 1995, and Mitchell, Brady, and Bonham 1994). Power analyses are now being performed on some LCTA databases to quantify the ability of the LCTA line-intercept method to detect certain changes in vegetation resources (Anderson et al. 1996). The requirements, cost and time to support the ITAM program including support and improvement of the LCTA component have been accepted by the Army's training community as proponents (USAEC 1996).

References

Anderson, A.B., P.J. Guertin, and D.L. Price, *Land Condition Trend Analysis: Power Analysis*, Technical Report (TR) 97/05 (U.S. Army Construction Engineering Research Laboratories [USACERL], October 1996).

Anderson, G.L., J.D. Hanson, and R.H. Haas, "Evaluating Landsat Thematic Mapper Derived Vegetation Indices for Estimating Above Ground Biomass on Semiarid Rangelands," *Remote Sensing of the Environment*, vol 45, No. 2 (1993), pp 165-175.

Arakeri, H.R., and R. Donahue, *Principles of Soil Conservation and Water Management*, (Rowman and Allanheld, NJ, 1984).

Arnold, J.G., J.R. Williams, A.D. Nicks, and N.B. Sammons, *SWRRB–A Basin Scale Simulator Model for Soil and Water Resources Management* (Texas A&M University Press, College Station, TX, 1990).

Arnold, J.G., B.A. Engel, and R. Srinivasan, "Continuous Time, Grid Cell Watershed Model," *Application of Advanced Information Technology: Effective Management to Natural Resources* (Am Soc of Agric Eng, Spokane, WA, 1993), p 267.

Bagnold, R.A., *The Physics of Blown Sand and Desert Dunes* (Methuen, London, UK,1941), p 256.

———, *The Physics of Blown Sand and Desert Dunes* (Wm. Morrow & Co., New York, NY, 1943), p 265.

Beasley, D.B., L.F. Huggins, and E.J. Monke,"ANSWERS: A Model for Watershed Planning," *Trans., ASAE*, vol 10 (1980), pp 485-492.

Blackburn, W.H., "Factors Influencing Infiltration and Sediment Production of Semiarid Rangelands in Nevada," *Water Resource Research*, vol 11 (1975), pp 929-937.

Bonham, C.D., *Measurement of Terrestrial Vegetation* (John Wiley & Sons, New York, 1989).

Chaces, H.M.L., and M.A. Nearing, "Uncertainty Analysis of the WEPP Soil Erosion Model," *Transactions of the American Society of Agricultural Engineers*, vol 34, No. 6 (1991), pp 2437-2444.

Chavez, P.S., D.J. Mackinnon, "Automatic Detection of Vegetation Changes in the Southwestern United States Using Remotely Sensed Images," *Photogrammetric Engineering and Remote Sensing*, vol 60, No. 5 (1994), pp 571-583.

Chepil, W.S., "The Transport Capacity of the Wind," *Soil Sci.*, vol 60 (1945), pp 475-480.

Decker, D.J., ed., *Challenges in the Conservation of Biological Resources—A Practitioner's Guide* (Westview Press, Boulder, CO, 1991).

Dee, R.F., T.W. Box, and E. Robertson, Jr., "Influences of Grass Vegetation on Water Intake of Pullman Silty Clay Loam," *Journal of Range Management*, vol 19 (1966), pp 77-79.

Dejong, S.M., "Derivation of Vegetative Variables From a Landsat TM Image for Modeling Soil Erosion," *Earth Surface Processes and Landforms*, vol 19, No. 2 (1994), pp 165-178.

Duley, F.L., and C.R. Domingo, *Effects of Grass on Intake of Water*, Nebraska Agricultural Experiment Station Research Bulletin 159 (1949).

Edwards, T.K., and G.D. Glysson, *Field Methods for Measurement of Fluvial Sediment*, U.S. Geological Survey Open-File Report 86-531 (Reston, VA, 1988).

Ellison, W.D., "Soil Erosion Studies," *Agr. Eng.*, vol 28 (1947), pp 145-146.

Foster, G.R., "Advances in Wind and Water Erosion Prediction," *Journal of Soil and Water Conservation*, vol 46, No. 1 (1991), pp 27-29.

Foster, G.R., and L.J. Lane, "Beyond the USLE: Advancements in Soil Erosion Prediction," *Future Developments in Soil Science Research* (Soil Sci. Soc. Am., Madison, WI, 1987), pp 315-326.

Franklin, S.E., "Discrimination of Subalpine Forest Species and Canopy Density Using Digital CASI, SPOT PLA, and Landsat TM Data," *Photogrammetric Engineering and Remote Sensing*, vol 60, No. 10 (1994), pp 1233-1241.

Gillette, D.A., "Wind Erosion," in M. G. Wolman, et al., eds., *Soil Conservation: Assessing the National Resources Inventory*, vol 2 (Nat. Academy Press, Washington, DC, 1986), pp 129-158.

Gillette, D.W., "Point-Quadrant Methods for the Analysis of Vegetation," *Australian Journal of Botany*, vol 1 (1953), pp 457-461.

Harrison, J., "Water Quality Standards for Erosion and Sedimentation: Building a Set of Protective Criteria," *Proceedings, DOD/Interagency Workshop on Technologies To Address Soil Erosion on DOD Lands*, FTN Associates, LTD., eds. (U.S. Army Engineer Waterways Experiment Station [USAWES], Vicksburg, MS, 1995), pp 275-278.

Heady, H.F., R.P. Gibbens, and R.W. Powell,"A Comparison of the Charting, Line Intercept, and Line Point Methods of Sampling Shrub Types of Vegetation," *Journal of Range Management*, vol 12 (1959), pp 180-188.

Heilman, J.L., and W.E. Boyd, "Soil Background Effects on the Spectral Response of Three-Component Rangeland Scene," *Remote Sensing of Environment*, vol 19 (1986), pp 127-137.

Heinz, R.A., "Hydrographic Surveying Turns to Electronics," *Civil Engineering*, vol 47, No. 4 (1977), pp 62-65.

International Organization for Standardization, "Methods for Measurement of Sediment Accumulation in Reservoirs," ISO/DIS 6421 (1982), pp 1-13.

Kauth, R.J., P.F. Lambeck, W. Richardson, G.S. Thomas, and A.P. Pentland, "Feature Extraction Applied to Agricultural Crops as Seen by Landsat," *Proceedings of the Technical Sessions Vol II, The LACIE Symposium* (National Aeronautics and Space Administration [NASA], Johnson Space Center, 1978).

Knisel, W.G., ed., "CREAMS: A Field Scale Model for Chemicals, Runoff, and Erosion From Agricultural Management Systems," Cons. Res. Rpt. No. 26 (Sci. and Educ. Admin., U.S. Dept. Agr., Washington, DC, 1980).

Konke, H., and A.R. Bertrand, *Soil Conservation* (McGraw-Hill, New York, 1959).

Kremer, R.G., and S.W. Running, "Community Type Differentiation Using NOAA/AVHRR Data Within a Sagebrush Steppe Ecosystem," *Remote Sensing of Environment*, vol 46, No. 3 (1993), pp 311-318.

Krupovage, J. "Sedimentation and Turbidity Issues on a Heavily Urbanized and Industrialized Air Force Installation," *Proceedings, DOD/Interagency Workshop on Technologies To Address Soil Erosion on DOD Lands*, FTN Associates, LTD., eds. (USAWES, 1995), pp 257-259.

Lauver, C.L., and J.L. Whistler, "A Hierarchical Classification of Landsat TM Imagery To Identify Natural Grassland Areas and Rare Species Habitat," *Photogrammetric Engineering and Remote Sensing*, vol 59, No. 5 (1993), pp 627-634.

Law, B.E., and R.H. Waring, "Remote Sensing of Leaf Area Index and Radiation Intercepted by Understory Vegetation," *Ecological Applications*, vol 4, No. 2 (1994), pp 272-279.

McGinty, W.A., F.E. Smeins, and L.B. Merrill, "Influence of Soil, Vegetation, and Grazing Management on Infiltration Rate and Sediment Production of Edwards Plateau Rangeland," *Journal of Range Management*, vol 32 (1979), pp 33-37.

Meeuwig, R.O., "Infiltration and Soil Erosion as Influenced by Vegetation and Soil in Northern Utah," *Journal of Range Management*, vol 23 (1970), pp 185-188.

Meyer, L.D., and D.L. McCune, "Rainfall Simulator for Runoff Plots," *Agricultural Engineering*, vol 39 (1958), pp 644-648.

Meyer, L.D., and W.H. Wischmeier, "Mathematical Simulation of the Process of Soil Erosion by Water," *American Society of Agricultural Engineers Transactions*, vol 12 (1969), pp 754-762.

Mitas, L., H. Mitasova, W.M. Brown, and M. Astley, "Interacting Fields Approach for Evolving Spatial Phenomena: Application to Erosion Simulation for Optimized Land Use," *Proceedings of the 3rd International Conference on Integration of Environmental Modeling and GIS, Santa Fe, NM*

(National Center for Geographic Information and Analysis, Santa Barbara, CA, 1996). Note: CD ROM publication.

Mitasova, H, L. Mitas, W.M. Brown, D.P. Gerdes, I. Kosinovsky, and T. Baker, "Modelling Spatially and Temporally Distributed Phenomena: New Methods and Tools for GRASS GIS," *International Journal of Geographical Information Systems*, vol 9 (1995), pp 433-446.

Mitasova, H., J. Hofierka, M. Zlocha, and L.R. Iverson, "Modelling Topographic Potential for Erosion Deposition Using GIS," *International Journal of Geographical Information Systems*, vol 10 (1996), pp 629-641.

Mitchell, J.E., W.W. Brady, and C.D. Bonham, *Robustness of the Point-line Method for Monitoring Basal Cover*, USDA Forest Service Research Note RM-528 (Rocky Mountain Forest and Range Experiment Station, Fort Collins, CO, 1994).

Moldenhauer, W.C., and W.H. Wischmeier, "Soil and Water Losses and Infiltration Rates on Ida Silt Loam as Influenced by Cropping Systems, Tillage Practices and Rainfall Characteristics," *Soil Science Society of America Proceedings,* vol 24 (1960), pp 409-413.

Moore, I.D., and J.P. Wilson, "Length-Slope Factors for the Revised Universal Soil Loss Equation: Simplified Method of Estimation," *Journal of Soil and Water Conservation*, vol 47, No. 5 (1992), pp 423-428.

Mueller-Dumbois, D., and H. Ellenberg, *Aims and Methods of Vegetation Ecology* (John Wiley & Sons, Inc., New York, 1974).

Musgrave, G.W., "The Quantitative Evaluation of Factors in Water Erosion, A First Approximation," *Journal of Soil and Water Conservation*, vol 2, No. 3 (1947), pp 133-138.

Parker, G., P.C. Klingeman, and D.G. McLean,"Bedload and Size Distribution in Paved Gravel Bed Streams," *Jour. Hydraul. Div. ASCE*, vol 108(HY4) (1982), pp 544-571.

Parker, R.S., "Identifying and Integrating Changes in Sediment Discharge From Altered Land Use," *Proceedings, DOD/Interagency Workshop on Technologies To Address Soil Erosion on DOD Lands,* FTN Associates, LTD., eds. (USAWES, 1995), pp 253-255.

Parker, R.S., and W.R. Osterkamp"Identifying Trends in Sediment Discharge From Alterations in Upstream Land Use" (International Association of Hydrological Sciences Symposium, Boulder CO, in Press).

Pickup, G., "Estimating Changes in Vegetation Cover Over Time in Arid Rangelands Using Landsat MSS Data," *Remote Sensing of the Environment,* vol 43, No. 3 (1993), pp 243-263.

Price, D.L., A.B. Anderson, W. Whitworth, and P.J. Guertin, *Land Condition Trend Analysis Data: Preliminary Summaries*, Technical Report N-95/39/ADA300753 (USACERL, September 1995).

Price, K.P., D.A. Pyke, L. Mendes, "Shrub Die Back in a Semiarid Ecosystem; The Integration of Remote Sensing and Geographic Information Systems for Detecting Vegetation Change," *Photogrammetric Engineering and Remote Sensing*, vol 58, No. 4 (1992), pp 455-463.

Renard, K.G., J.M. Laflen, G.R. Foster, and D.K. McCool, "The Revised Universal Soil Loss Equation," in: R. Lal, ed., *Soil Research Methods* (Soil and Water Conservation Society, Ankeny, IA , 1994), pp 105-124.

Renthall, J., "Evaluating and Reducing Sedimentation on the Public Lands: Case Histories," *Proceedings, DOD/Interagency Workshop on Technologies To Address Soil Erosion on DOD lands,* FTN Associates, LTD., eds. (USAWES, 1995), pp 227-238.

Satterwhite, M.B., "Discriminating Vegetation and Soils Using Landsat MSS and Thematic Mapper Bands and Band Ratios," *50th Ann. Meeting American Society Photogrammetry*, vol 2 (American Society of Photogrammetry, Falls Church, VA, 1984), pp 479-490.

Skinner, J.V., and J.P. Beverage, "Continuous Measurement of Suspended-Sediment Concentration," in Shou-Shen Fan and Yung-Huang Kuo (eds.), *Proceedings of the Fourth Federal Interagency Sedimentation Conference*, vol 1 (1986), pp 1-29 to 1-39.

Skinner, J.V., and J.J. Szalona, "Gages for Measuring Fluvial-sediment Concentration," in Shou-Shen Fan and Yung-Huang Kuo (eds.), *Proceedings of the Fifth Federal Interagency Sedimentation Conference*, vol 1 (1991), pp 2-1 to 2-8.

Smith, A.M., D.J. Major, M.J. Hill, W.D. Williams, B. Brisco, C.W., Lindwall, and R.J. Brown, "Airborne Synthetic Aperture Radar Analysis of Range Land Revegetation of a Mixed Prairie," *Journal of Range Management*, vol 47, No. 5 (1994), pp 385-391.

Smith, D.D., and D.M. Whitt, "Estimating Soil Losses From Field Areas of Claypan Soils," *Soil Science Society of America Proceedings*, vol 12 (1947), pp 485-490.

Smith, D.D., and W.H. Wischmeier, "Factors Affecting Sheet and Rill Erosion," *American Geophysical Union Transactions*, vol 38 (1957), pp 889-896.

Smith, L., "Technical Challenges for Soil and Water Resources Stewardship in DOD," *Proceedings, DOD/Interagency Workshop on Technologies To Address Soil Erosion on DOD Lands,* FTN Associates, LTD., eds. (USAWES, 1995), pp 191-194.

Srinivasan, R., B.A. Engel, J.R. Wright, J.G. Lee, and D.D. Jones, "Impact of GIS-Derived Topographic Attributes on the Simulation of Erosion Using AGNPS," *Applied Engineering in Agriculture*, vol 10, No. 4 (1994), pp 561-566.

Tazik, D.J., S.D. Warren, V.E. Diersing, R.B. Shaw, R.J. Brozka, C.F. Bagley, and W.R. Whitworth, *U.S.Army Land Condition Trend Analysis (LCTA) Plot Inventory Field Methods*, TR N-92/03/ADA247931 (USACERL, February 1992).

Thurow, T.L., *Hydrologic Interrelationships With Vegetation and Soil as Affected by Selected Livestock Grazing Systems and Climate on the Edwards Plateau*, Ph.D. Dissertation (Texas A&M University, College Station, TX, 1985).

Thurow, T.L., S.D. Warren, and D.H. Carlson, "Tracked Vehicle Traffic Effects on the Hydrologic Characteristics of Central Texas Rangeland," *Transactions of the American Society of Agricultural Engineers*, vol 36 (1993), pp 1645-1650.

Tucker, C.J. "Red and Photographic Infrared Linear Combinations for Monitoring Vegetation," *Remote Sensing of Environment*, vol 8 (1979), pp 121-150.

U.S. Air Force, *Natural Resources Management Plan* (Eglin Air Force Base, FL, 1993).

U.S. Army Corps of Engineers, *Users Manual, SSARR Model* (Portland, OR, 1989).

Walker, B.H., "Ecological Considerations in the Management of Semi-arid Ecosystems in South-Central Africa," *Proceedings 1st International Congress of Ecologists* (1994), pp 124-129.

Wenger, K.F., ed., *Forestry Handbook*, 2d ed. (John Wiley & Sons, New York, 1984).

Williams, J.R., *Sediment-yield Prediction With the Universal Equation Using a Runoff Energy Factor*, ARS-S-40 (U.S. Department of Agriculture, 1975), pp 244-252.

Williams, J.R., K.G. Renard, and P.T. Dyke, "EPIC: A New Method for Assessing Erosion's Effect on Soil Productivity," *J. Soil and Water Conservation*, vol 38, No. 5 (1983), pp 381-383.

Wischmeier, W.H.,"A Rainfall Erosion Index for a Universal Soil-Loss Equation," *Soil Science Society of America Proceedings*, vol 23 (1959), pp 246-249.

———"Estimating the Soil Loss Equation's Cover and Management Factor for Undisturbed Areas," ARS-S-40, *Sediment Yield Workshop Proceedings* (U.S. Department of Agriculture, Oxford, MS, 1975).

———"Use and Misuse of the Universal Soil Loss Equation," *Journal of Soil and Water Conservation*, vol 31, No. 1 (1976), pp 5-9.

Wischmeier, W.H., and D.D. Smith, "Predicting Rainfall Erosion Losses From Cropland East of the Rocky Mountains," *Agriculture Handbook No. 282* (U.S. Department of Agriculture, Washington, DC, 1965).

Wolfe, D., C. Liu, J. Maresk, S. Perry, G. Rowell, and D. Diamond, "A Landcover Analysis of Texas National Guard Training Sites," *Proceedings, DOD/Interagency Workshop on Technologies To Address Soil Erosion on DOD Lands,* FTN Associates, LTD., eds. (USAWES, 1995), pp 275-278.

Woodruff, N.P., and F.H. Siddoway, "A Wind Erosion Equation," *Soil Sci. Soc. Amer. Proc.*, vol 29 (1965), pp 602-608.

Woodward, L., "Infiltration Capacities on Some Plant-Soil Complexes on Utah Range Watershed Lands," *Transactions of American Geophysics Union*, No. 24 (1943), pp 468-475.

Zhuang, H.C., M. Shapiro, C.F. Bagley, "Relaxation Vegetation Index in Non-Linear Modeling of Ground Plant Cover by Satellite Remote Sensing Data," *International Journal of Remote Sensing*, vol 14, No. 18 (1993), pp 3447-3470.

Zhang, X.C., M.A. Nearing, L.M. Risse, and K.C. McGregor, "Evaluation of the WEPP Runoff and Soil Loss Predictions Using Natural Runoff Plot Data," *Transactions of the American Society of Agricultural Engineers*, vol 39, No. 3 (1996), pp 855-863.

Zingg, R.W., "Degree and Length of Land Slope as it Affects Soil Loss in Runoff," *Agricultural Engineering*, vol 21 (1940), pp 59-64.

Bibliography

Chepil, W.S., and N.P. Woodruff, *Estimations of Wind Erodibility of Farm Fields*, USDA Prod. Res. Rpt. no. 25 (1959).

Dissmeyer, G.E., *Evaluating the Effectiveness of Forestry Best Management Practices in Meeting Water Quality Goals or Standards* (USDA Forest Service, Atlanta, GA, 1994).

Fisher, P.S., and E.L. Skidmore, *WEROS: A Fortran IV Program To Solve the Wind Erosion Equation*, ARS 41-174 (U.S. Department of Agriculture, 1970).

Guerard, von. P., R.S. Parker, and R.G. Dash, *Assessment of Effects of Military Maneuvers on the Streamflow, Water Quality, and Sediment Yields at the U.S. Army Pinon Canyon Maneuver Site, Las Animas County, Colorado*, Water-Resources Investigations Report 91-4095 (U.S. Geological Survey, Denver, CO, 1993), 83pp.

Goodall, D.W., "Some Considerations in the Use of Point Quadrants for the Analysis of Vegetation," *Australian Journal of Scientific Research* (1952) Series B, pp 5, 1-41.

Horowitz, A.J., F.A. Rinella, P. Lamothe, T.L. Miller, T.K. Edwards, R.L. Roche, and D.A. Rickert, "Cross-Sectional Variability in Suspended Sediment and Associated Trace Element Concentrations in Selected Rivers in the U.S.," *Sediment and the Environment (Proceedings of the Baltimore Symposium*, IAHS Publ. No. 181 (May 1989), pp 56-66

Macia, T.E., *Army Reinvents Training Land Protection; Operators Take the Lead, Proceedings of the 22nd Environmental Symposium & Exhibition* (Orlando, FL, 18-21 March 1996).

Nelson, J.M., W.W. Emmett, and J.D. Smith, "Flow and Sediment Transport in Rough Channels," in Shou-Shen Fan and Yung-Huang Kuo, eds., *Proceedings of the Fifth Federal Interagency Sedimentation Conference*, vol 1 (1991), pp 455-462.

Pacific Southwest Inter-Agency Committee, *Report on Factors Affecting Sediment Yield in the Pacific Southwest Area* (Water Management Subcommittee, Sedimentation Task Force, 1968).

Skidmore, E.L., and N.P. Woodruff, *Wind Erosion Forces in the United States and Their Use in Predicting Soil Loss*, USDA Agriculture Handbook No. 346 (1968).

U.S. Army Land Inventory Advisory Committee, *Report of LCTA Review* (Washington, DC, 1989).

U.S. Environmental Protection Agency (USEPA), *Biological Criteria: Technical Guidance for Streams and Small Rivers*, EPA 822-B-94-001 (USEPA, Office of Water, Washington, DC, 1994).

U.S. Environmental Protection Agency, *Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters*, EPA-840-B-92-002 (USEPA, Office of Water, Washington, DC, January 1993).

Walling, D.E., and B.W. Webb, "The Reliability of Suspended Sediment Load Data, Erosion and Sediment Transport Measurement," *Proceedings of the Florence Symposium*, IAHS Publ. No. 133 (1981), pp 177-194.

Wischmeier, W.H., and D.D. Smith, "Predicting Rainfall Erosion: A Guide to Conservation Planning," *Agr. Handbk*. 537 (U.S. Department of Agriculture, Washington, DC, 1978).

U.S. Army Environmental Center (USAEC), *Land Condition Trend Analysis II (LCTA II): Workshop Report 29* (March 1996).

Appendix A: The WEPP Model and its Applicability for Predicting Erosion on DOD Areas

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Abstract

The Water Erosion Prediction Project (WEPP) model is intended to replace the Universal Soil Loss Equation for predicting soil erosion. WEPP is a fundamental process-based model that operates on a daily time step to estimate land, soil and vegetation conditions when a rainfall event occurs, and then uses this information to predict the hydrology and erosion of single events. WEPP is used in conjunction with an input climate data file; long term estimates are based on the accumulated erosion occurring over the period of record covered by the input climate file. This paper describes the application of WEPP for making estimates of the land, soil and vegetation conditions, and their effect on soil erosion estimates. Additionally, shortcomings and advantages of WEPP for erosion prediction is discussed.

WEPP brings to the natural resource manager a tool for not only the evaluation of the impacts of management on soil erosion, but also for the evaluation of offsite impacts related to management decisions.

Introduction

The USLE (Universal Soil Loss Equation, Wischmeier and Smith, 1965, 1978) and its revision RUSLE (Revised USLE, Renard et al., 1991) is an erosion prediction technology that has served mankind well. However, because of its empirical nature, it has proven to be difficult to apply in some cases, particularly to offsite problems.

Additionally, the empirical database to support its application to unique situations is very small.

In 1969, Meyer and Wischmeier presented a model of the water erosion process that was more basic in nature. The CREAMS model (Chemicals, Runoff and Erosion from Agricultural Management Systems, U.S. Dept. Agr., 1980) included the more fundamental processes of water erosion and sediment transport. A more recent effort was initiated to replace the USLE with fundamental erosion process technologies in a broad based project titled WEPP (Water Erosion Prediction Project, Foster and Lane, 1987; Nearing and Lane, 1989).

WEPP is ready for use at the field level. Work will continue on WEPP to further improve its ability to predict soil erosion and sediment delivery and to improve its user friendliness. Work will be required to apply WEPP and to develop parameters for its application to specific conditions. Considerable work is required by action agencies to prepare for implementation. These efforts include training, selection of equipment, development of input data sets, and development of guidelines and procedures for use of WEPP. These are major tasks and require considerable time and effort.

WEPP is a well programmed maintainable model, with continuing efforts to improve performance and to apply sophisticated analysis to improving the code to ensure maintainability. Additionally, it is expected that a partnership of the initial federal agencies, plus other partners, will develop a structure for managing model improvements and insuring that updates are effective and timely.

This paper is not intended to be a overall examination of all components of the model, but rather a look at model components that are most important in representing DOD conditions. These components are related to hydrology, plant growth, erosion, and soil.

Description of WEPP

WEPP is a daily simulation model that computes the conditions of the soil and plant system that are important in runoff and soil erosion. If rainfall occurs, WEPP computes surface runoff. If surface runoff occurs, WEPP computes the soil that is detached and deposited down a hill slope and the amount delivered to a channel at the foot of a slope. These are all computed in the hill slope version of WEPP. Two additional versions (watershed or grid) are used to compute the erosion, deposition and delivery of sediment through the channel system on the area of interest.

WEPP represents the area where sheet and rill erosion occurs as a series of overland flow elements (OFE) beginning at the top of the slope and ending at a field boundary or a channel at the bottom of a slope. Each OFE is homogeneous with regard to the ecosystem, soil, and management.

Within an OFE, sediment detachment and transport occurs on rill and interrill areas. On interrill areas, the detachment is caused by raindrop impact, and transport is in very shallow flows that are impacted by raindrops. The detached and transported soil on an interrill area is delivered to a rill. Sediment detachment in a rill is caused by the hydraulic shear of the flow carried by the rill and is not affected by raindrops on the water surface. Sediment transport in a rill is also not affected by rainfall. Sediment deposition may occur in a rill if sediment load exceeds the transport capacity of the flow.

Plant Growth

The status of plants and plant residue when an erosion event occurs is vital to accurate estimation of soil detachment and transport. The status of below and above ground biomass must be accurately estimated to evaluate the effect of various management alternatives on soil erosion. WEPP calculates on a daily basis plant growth and the decomposition and accumulation of residue and litter.

Important plant growth characteristics include canopy cover and height, mass of live and dead below and above ground biomass, leaf area index and basal area, residue, and litter cover. Information about management is input to the model. Many annual and perennial crops, management systems and operations that may occur on cropland, rangeland, forestland, pastures, vineyards and gardens have been parameterized. Major efforts are underway to develop an expert system for selection of parameters to use in WEPP (Deer-Ascough et al., 1993). While this work is presently for cropland parameters, it is expected that parameters for rangelands and forestlands may eventually be included.

Decomposition is important in estimating residue and litter cover and soil erosion on rangelands and croplands. Coefficients for use in estimating litter and residue decomposition have been determined for many crops, but there has been little work on estimation of decomposition rates of surface litter found on rangelands and forestlands. However, this work is underway.

Hydrology

The hydrologic cycle must be well represented if erosion and sediment delivery are to be accurately predicted. WEPP uses several climate variables, including storm rainfall amount and duration, ratio of peak rainfall intensity to average rainfall intensity, time to peak intensity, daily maximum and minimum temperature, daily miles of wind by station and its direction, and solar radiation. These variables are required in components related to plant growth and surface litter decomposition, water balance, and in estimating runoff volume, duration and peak rate.

The hydrologic component of the WEPP hill slope profile model is derived from the research Infiltration and Runoff Simulator (IRS) model (Stone et al., 1992). IRS is an event-based model that uses the Green-Ampt Mein-Larson (GAML) infiltration equation as modified by Chu (1978), and the kinematic wave equations as presented by Lane et al. (1988).

Several modifications have been incorporated into the IRS model to address the implementation constraints of simplicity and speed of execution. Rainfall disaggregation (Nicks and Lane, 1989) of daily precipitation was added to reduce the amount of data needed to describe rainfall intensity needed by both the GAML model and the interrill erosion model. An approximate method for computing the peak discharge at the bottom of a hill slope profile (Hernandez et al., 1989) was added to reduce model run time. Parameters for the hydrologic component can be identified through calibration, if observed data are available or estimated by the model from measurable physical properties of the soil and vegetation (Rawls et al., 1983; Weltz et al., 1992). In continuous simulation mode, baseline hydrologic parameters are adjusted in response to changes in canopy cover and litter caused either by vegetation growth and decomposition, herbicide application, burning or grazing by animals.

Preliminary testing of the WEPP model on rangelands has been started using data from the semiarid rangeland Walnut Gulch Experimental Watershed. Tiscareno et al. (1992) found that the hydrologic response of the hill slope model is most sensitive to rainfall amount, duration, and GAML baseline saturated hydraulic conductivity. For a given runoff producing rainfall event, the response is most sensitive to GAML baseline saturated hydraulic conductivity, soil moisture, and above ground biomass. The parameter estimation techniques within the model and the procedure used to disaggregate rainfall events have been identified (van der Zweep et al. 1991) as critical components of the model requiring additional research. Improvements in estimation of the GAML baseline saturated hydraulic conductivity parameter and

in adjusting its baseline value to account for the influence of changes in canopy cover and surface litter may greatly improve model accuracy.

Erosion

WEPP models erosion on a hill slope by dividing the soil surface into two regions: rill (concentrated flow paths) and interrill. Rills are flow paths which form as water flow concentrates. Detachment in these channels is largely a function of flow shear stress (force exerted by water flow on the bed and banks). In many landscapes, these flow paths form at fairly regular intervals.

The area between rill channels is called the interrill area. Water flow on interrill areas is shallow, and most of the soil detachment here is due to raindrops impacting the soil surface. The raindrops also act to enhance the transport of previously detached sediment from the interrill area to the rill channels. Rills are the major sediment transport pathway for all sediment detached, both that from the rills and that supplied to the rills from the interrill areas.

The basic equation used in the WEPP erosion component is a steady state sediment continuity equation:

$$dG/dx = Di + Dr \qquad [1]$$

where G is sediment load in the flow down a hill slope (kg/s/m), x is distance downslope (m), Di is the interrill sediment delivery rate to the rills ($kg/s/m^2$) and Dr is the rill detachment or deposition rate ($kg/s/m^2$) (Nearing et al., 1989; Foster et al., 1989). For erosion computations for each individual storm, the time period used is the effective duration of runoff computed in the hydrology component of the model. Estimates of dG/dx are made at a minimum of 100 points down a profile, and a running total of the sum of all detachment and deposition at each point from each storm is used to obtain monthly, annual, and average annual values for the simulation.

The interrill component of WEPP is currently a fairly simple sediment delivery function:

$$Di = Ki\ Ie^{q}\ Ge\ Ce\ Sf \qquad [2]$$

where Di is delivery of detached sediment to the rill (kg/m^2), Ki is the interrill erodibility ($kg/s/m^4$), Ie is the effective rainfall intensity (m/s) occurring during the period of rainfall excess, q is peak runoff rate (m/s), Ge is a ground cover effect

adjustment factor, Ce is a canopy cover effect adjustment factor, and Sf is a slope adjustment factor. Ie is computed through a procedure that examines the time period over which rainfall excess is occurring. The effective duration of rainfall excess is passed to the erosion component from the hydrology component. Equation 2 lumps together the processes of detachment, transport and deposition on the interrill areas.

Ce is a function of the fraction of the soil surface area covered by canopy and the height of the canopy. Ge is a function of the fraction of the interrill area covered by surface litter, residue, and rocks. Sf is a function of the interrill slope:

$$Sf = 1.05 - 0.85\ e^{(-4 \sin B)} \quad [3]$$

where B is the interrill slope angle. These functions are based on reasonable fits to data reported by Meyer (1981), Meyer and Harmon (1984, 1989), and Watson and Laflen (1986).

Concentrated flow paths are the major pathway for sediment movement down most hill slopes. Water flowing in such rills has the ability to both transport sediment and detach additional soil. When the rill flow becomes laden with sediment from either sediment supplied from the interrill areas or from sediment detached in the rill channel itself, the rill flow loses some of its ability to detach soil and transport sediment. If too much sediment is supplied and the flow system is overloaded, then no rill detachment can take place, and sediment deposition occurs. One of the strengths of WEPP is its ability to estimate both rill detachment and deposition, allowing comprehensive evaluation of both on-site and off-site effects of erosion.

WEPP uses separate equations to simulate rill detachment and deposition. Rill detachment is predicted to occur when the flow shear stress exerted on the soil exceeds a critical threshold value, and sediment transport capacity is greater than the sediment load:

$$Dr = Kr\ (TAU - TAUc)\ (1 - G/Tc) \quad [4]$$

where Dr is the rill detachment rate ($kg/s/m^2$), Kr is the adjusted rill erodibility parameter (s/m), TAU is the flow shear stress (Pa), TAUc is the critical flow shear stress (Pa), G is sediment load (kg/s/m) and Tc is the flow sediment transport capacity (kg/s/m). One can see from this equation that as the flow fills with sediment (G approaches Tc) that the rill detachment rate will be predicted to decrease. Sediment transport capacity in the WEPP model is predicted using the equation:

$$Tc = kt\ TAU^{1.5} \quad [5]$$

where kt is a transport coefficient ($m^{0.5}\ s^2 / kg^{0.5}$) calibrated and obtained by applying the Yalin (1963) equation at the end of the slope profile (Finkner et al., 1989).

When the sediment load exceeds the sediment transport capacity, the equation used by WEPP to predict deposition is:

$$Dr = ((BETA^*\ Veff)/q)\ (Tc - G) \quad [6]$$

where Dr is the rill deposition rate ($kg/s/m^2$), BETA is a rainfall-induced turbulence factor (currently set to 0.5), Veff is an effective particle fall velocity (m/s), and q is flow discharge per unit width (m^2/s). An area of concern with the current deposition equation is the estimation of the Veff term based on the particle size distribution. An evaluation of the procedure which uses the smallest size classes is underway to determine how well the method and the deposition equation perform. Other areas for future improvement in the prediction of deposition would be to: (1) compute the BETA coefficient as a function of rainfall intensity and flow depth, instead of assigning it a constant value, and (2) alter the sediment transport equation used so that it includes a rainfall-enhancement term.

Rill characteristics such as spacing, width and shape are important in estimating soil erosion. For rangelands, rill spacing is estimated as the average spacing of vegetation but spacing is never less than 0.5 m or greater than 5 m. Estimation of rill width is based on flow and topographic characteristics, while rill shape is always assumed to be rectangular. These assumptions are being evaluated and are subject to change as additional information becomes available. Sensitivity analyses to date have indicated that rill characteristics are not as significant as several other characteristics in determining erosion and sediment delivery.

Soil

The soil component deals with temporal changes in soil properties important in the erosion process, and in estimation of surface runoff rates and volumes. These include random roughness, ridge height, saturated hydraulic conductivity, soil erodibilities and bulk density. The effects of tillage, weathering, consolidation and rainfall are considered in estimating the status of soil properties.

Baseline interrill and rill erodibility, and critical hydraulic shear for a freshly tilled condition, are adjusted to other conditions based on time since tillage for cropland soils. For rangeland soils, the baseline condition is that of a long-term undisturbed

soil under rangeland conditions with surface residue removed. For both range and cropland soils, adjustments to interrill erodibility are based on live and dead roots in the upper 150 mm of the soil and to rill erodibility because of incorporated residue in the upper 150 mm of the soil.

Past efforts to model erosion processes have used USLE relationships for estimating soil erodibility. A major WEPP effort has been extensive field studies (Elliot et al., 1989; Simanton et al., 1987) to develop the technology to predict erodibility values for cropland and rangeland soils from soil properties. A major effort continues for both rangelands and croplands to expand the data bases that support WEPP.

WEPP Interface

Successful use of any computer program requires a user friendly interface, and WEPP is no exception. Presently, there are no widely accepted standards for developing interfaces for natural resource models. Such standards are needed to fully develop the use of computer models for natural resource management decision making.

The user interface is used to build, modify, load and store all input data files. Programs that build the soils, climate (CLIGEN), topographic, management and watershed files are accessed from the interface. The building of a management file is accomplished using crop and tillage operations databases. These databases can be modified from the management file builder to adjust for different crops or tillage machinery.

The interface is also used to select output. There is a wide variety of outputs available. These include daily information on soil moisture, residue, biomass, canopy, runoff, and soil erosion. Also available are event, monthly and average annual values of runoff, soil detachment, soil deposition, and sediment delivery. Size distribution of sediment delivered is also computed for these periods. Information is also available for irrigation and for winter conditions.

The interface also produces two graphical outputs. One of these is the distribution of erosion and deposition down the slope. Another allows for plotting of various variables on up to six different graphs at once. As an example, one could plot sediment delivery versus runoff volume, canopy cover versus days in the simulation, or water storage for individual soil layers versus days in simulation. Almost any variable computed by WEPP is available for use in the graphical output.

The interface allows for batch operation. Multiple runs can be set up and run unattended. All input data files are checked before any runs are made, and error files are generated for use in troubleshooting. Individual runs are named, and output files generated are based upon these names and appropriate file extensions.

Availability

The WEPP hill slope and watershed models and interfaces, along with databases, user guides and supporting information are available on the INTERNET. These can be retrieved following the instructions appended to this paper. Additionally, the proceedings of a Soil and Water Conservation Society (Ankeny, Iowa) sponsored symposium (1995) will contain much of the WEPP information.

Databases are available. A climate file can be generated for almost any location in the United States using the climate information available on the INTERNET. Similarly, a soils data base is available for the dominant phase of every soil type in the United States, also on the INTERNET. The crop parameter expert system (CPIDS) is also part of the WEPP package available on the INTERNET. Default databases are available for various yield levels for much of the United States where these crops are commonly grown. Databases are available for many rangeland conditions.

Testing

Extensive testing of WEPP has been conducted, and still continues. WEPP has been tested on long term natural runoff plots at numerous sites around the United States. It has been tested on forest and rangeland sites. It has been tested in Canada, Austria, Portugal, and Italy. Testing is underway for the watershed version. Most reports seem to indicate that WEPP is performing satisfactorily. Additional testing is planned in other countries and for other conditions.

Summary

The WEPP model for soil erosion prediction is being developed to work for all land situations in the United States. Its major limitations on DOD lands are accurate representation and parameterization of the DOD activities on these lands. It is expected that these limitations will not be extremely difficult to overcome. Some programming of the interface will be required for best use by DOD.

WEPP brings to the manager's tool kit a new tool that provides new information of importance not only for protection of the soil and land resources, but for evaluation of offsite impacts of DOD management and conservation practices. As the demands of the twenty-first century increase our reliance on a dwindling natural resource base, WEPP and other natural resource models will assume greater roles in management of these resources.

References

Chu, S.T. 1978. "Infiltration during an unsteady rain." *Water Resour. Res.* 14(3): 461-466.

Deer-Ascough, L.A., G.A. Weesies, J.C. Ascough II, D. E. Stott, and J. M. Laflen. 1993. "Plant database development and linkage with a knowledge-based system for use in erosion prediction models." In: *Proceedings, Application of Advanced Information Technologies for Management of Natural Resources*, Spokane, WA, June 18-19, 1993. Available from Am. Soc. Agric. Eng., St. Joseph, Michigan (In press).

Elliot, W.J., A.M. Leibenow, J.M. Laflen and K.D. Kohl. 1989. *A compendium of soil erodibility data from WEPP cropland soil field erodibility experiments 1987 and 1988*. NSERL Report No. 3, National Soil Erosion Research Laboratory, USDA-ARS, West Lafayette, Indiana.

Finkner, S.C., M.A. Nearing, G.R. Foster and J.E. Gilley. 1989. "A simplified equation for modeling sediment transport capacity." *Trans. Am. Soc. Agric. Eng*. 32(5):1545-1550.

Foster, G.R. and L.J. Lane. 1987. *User Requirements: USDA-Water Erosion Prediction Project (WEPP)*. NSERL Report No. 1, National Soil Erosion Research Laboratory, USDA-ARS, West Lafayette, Indiana.

Foster, G.R., L.J. Lane, M.A. Nearing, S.C. Finkner, and D.C. Flanagan. 1989. "Erosion Component. p 10.1-10.12." In: L. J. Lane and M. A. Nearing (ed.). *USDA-Water Erosion Prediction Project: Hillslope Profile Model Documentation*. NSERL Report No. 2. USDA-ARS National Soil Erosion Research Laboratory, Purdue University. West Lafayette, Indiana.

Hernandez, M., L.J. Lane, and J.J. Stone. 1989. "Surface Runoff." p 5.1-5.18. In: L. J. Lane and M. A. Nearing (ed.). *USDA-Water Erosion Prediction Project: Hillslope Profile Model Documentation*. NSERL Report No. 2. USDA-ARS National Soil Erosion Research Laboratory, Purdue University. West Lafayette, Indiana.

Johnson, C.W., G.A. Schumaker, and J.P. Smith. 1980. "Effects of grazing and sagebrush control on potential erosion." *J. Range Manage*. 33: 451-454.

Laflen, J.M., W.J. Elliot, J.R. Simanton, C.S. Holzhey, and K.D. Kohl. 1991. "WEPP: soil erodibility experiments for rangeland and cropland soils." *J. Soil Water Cons*. 46(1): 39-44.

Lane, L.J., E.D. Shirley, and V.P. Singh. 1988. "Modeling erosion on hillslopes." p 287-308. In: M. G. Anderson (ed.). *Modeling Geomorphic Systems*. John Wiley and Sons, New York.

Lindley, M.R., B.J. Barfield, B.N. Wilson, and J.M. Laflen. 1992. *The surface impoundment element for WEPP-Farm pond hydraulics*. Paper No. 92-2643. Am. Soc. Agric. Eng., St. Joseph, Michigan 1992 (Technical Report).

Meyer, L.D. 1981. "How rain intensity affects interrill erosion." *Trans. Am. Soc. Agric. Eng*. 24: 1472-1475.

Meyer, L.D. and W.H. Wischmeier. 1969. "Mathematical simulation of the process of soil erosion by water." *Trans. Am. Soc. Agric. Eng*. 12: 754-762.

Meyer, L.D. and W.C. Harmon. 1984. "Susceptibility of agricultural soils to interrill erosion." *Soil Sci. Soc. Am. J*. 48: 1152-1157.

Meyer, L.D. and W.C. Harmon. 1989. "How row-sideslope length and steepness affect sideslope erosion." *Trans. Am. Soc. Agric. Eng*. 32: 639-644.

Nearing, M.A. and L.J. Lane. 1989. *USDA-Water erosion prediction project: Hillslope profile model documentation*. NSERL Report No. 2, National Soil Erosion Research Laboratory, USDA-ARS, West Lafayette, Indiana.

Nearing, M.A., G.R. Foster, L.J. Lane and S.C. Finkner. 1989. "A process-based soil erosion model for USDA-Water Erosion Prediction Project technology." *Trans. Am. Soc. Agric. Eng*. 32: 1587-1593.

Nicks, A.D. and L.J. Lane. 1989. Ch. 2. "Weather Generator." p 2.1-2.19. In: L. J. Lane and M. A. Nearing (ed.). *USDA-Water Erosion Prediction Project: Hillslope Profile Model Documentation*. NSERL Report No. 2. USDA-ARS National Soil Erosion Research Laboratory, Purdue University. West Lafayette, Indiana.

Rawls, W.J., D.L. Brakensiek, and N. Miller, 1983. "Green-Ampt infiltration parameters from soils data." *J. Hyd. Eng*. 109(1): 62-70.

Renard, K.G., G.R. Foster, G.A. Weesies, and J.P. Porter. 1991. "RUSLE: Revised Universal Soil Loss Equation." *J. Soil and Water Cons*. 46(1): 30-33.

Simanton, J.R., M.A. Weltz, L.T. West, and G.D. Wingate. 1987. *Rangeland experiments for water erosion prediction project*. Paper No. 87-2545. Am. Soc. Agric. Eng., St. Joseph, Michigan.

Stone, J.J., L.J. Lane, and E.D. Shirley, 1992. "Infiltration and runoff simulation on a plane." *Trans. Am. Soc. Agric. Eng*. 35(1): 161-170.

Tiscareno, M., V.L. Lopes, and J.J. Stone. 1992. *Sensitivity of the WEPP Watershed model for rangeland conditions*. Paper No. 92-2018, Am. Soc. Agric. Eng., St. Joseph, Michigan.

U.S. Department of Agriculture. 1980. *CREAMS - A field scale model for chemicals, runoff, and erosion from agricultural management systems*. Conservation Research Report No. 26. U.S. Department of Agriculture, Science and Education Administration, U.S. Government Printing Office, Washington, DC.

van der Zweep, R., V.L. Lopes, and J.J. Stone. 1991. *Validation of the WEPP Watershed Model*. Paper No. 91-2552, Am. Soc. Agric. Eng., St. Joseph, Michigan.

Watson, D.A. and J.M. Laflen. 1986. "Soil strength, slope, and rainfall intensity effects on interrill erosion." *Trans. Am. Soc. Agric. Eng*. 29: 98-102.

Weltz, M.A., A.B. Arslan, and L.J. Lane. 1992. "Hydraulic roughness coefficients for native rangelands." *ASCE Irrigation and Drainage*. 118(5): 776-790.

Wischmeier, W.H. and D.D. Smith, 1965. *Predicting rainfall-erosion losses from cropland east of the Rocky Mountains-Guide for selection of practices for soil and water conservation*. Agricultural Handbook No. 282. U.S. Department of Agriculture, U.S. Government Printing Office, Washington, DC.

Wischmeier, W.H. and D.D. Smith. 1978. *Predicting rainfall erosion losses*. Agriculture Handbook No. 537. U.S. Department of Agriculture, Science and Education Administration, U.S. Government Printing Office, Washington, DC.

Yalin, Y.S. 1963. "Am expression for bed-load transportation." *J. Hydraulic Div*., Am. Soc. Civil. Eng. 89 (HY3): 221-250.

Annex A1: To Transfer WEPP Files to Your PC via the INTERNET

1. Using the FTP program, connect to the file server storing the WEPP and CPIDS programs by typing: FTP soils.ecn.purdue.edu

2. Logon as anonymous. Enter your name as the password.
   Name: anonymous
   Password: yourname

3. Set the transfer type to binary by typing: binary

4. Set for noninteractive transfer by typing: prompt

5. Move to the directory of choice:
   cd pub/wepp/wepp.??? (for the DOS executable WEPP programs)
   [WEPP.??? extension depends on current version]
   cd pub/wepp/document (for the WEPP??? user summary doc)
   cd pub/wepp/cligen (for the CLIGEN program or state files)
   cd pub/wepp/cligen/maps (for the climate file builder map files)
   cd pub/cpids (for CPIDS programs and database)

6. Get the desired file(s) using the GET or MGET commands by typing:
   mget *.* OR
   get cligen31.exe (for example)

7. Quit the FTP program by typing: quit

To Install WEPP Programs from a Hard Drive on a DOS computer:

1. Place the 3 installation executable files (WINSTALL.EXE, WDIST1.EXE, WDIST2.EXE) in the same directory on your drive

2. Move to this directory and type:
   WINSTALL

3. This will automatically install the WEPP/Shell programs on the hard drive/disk partition of your choice. You will be prompted for a change of diskettes [since the information for disk 2 (the WDIST2.EXE file) is already present, enter Yes].

To Use the WEPP programs after Installation:

Once installed, the WEPP programs are run by typing: SHELL when in the \WEPP\DIST directory. See the next page for the directory structure created during the WEPP installation.

The programs will prompt you for corrections if things are found not to be in order.

WEPP Installed Files

The following files and directories will be created during a WEPP installation:

\WEPP\DIST\README.1ST (important notes on usage)
\WEPP\DIST\SHELL.BAT (entry-point for using the WEPP shell)
\WEPP\DIST\WEPPKIDS.DEF (common paths and defaults file)
\WEPP\DIST\UTIL <DIR> (utilities for cloning the programs)
\WEPP\DIST\SHELL <DIR> (the WEPP/Shell program)
\WEPP\DIST\WEPP <DIR> (the WEPP model)
\WEPP\DIST\INPUT <DIR> (input files and builders)
\INPUT\MAN <DIR> (WMAN management file builder & files)
\INPUT\SLOPE <DIR> (WSLP slope builder and files)
\INPUT\SOIL <DIR> (WSOL soil builder and files)
\INPUT\CLIMATE <DIR> (CLIGEN climate builder and files)
\INPUT\IRR <DIR> (WIRR irrigation builder and files)
\WEPP\DIST\OUTPUT <DIR> (output files and viewers)
\OUTPUT\WGR <DIR> (WWGR graphical viewer)
\OUTPUT\PLOT <DIR> (EGRAPH graphical viewer)
\OUTPUT\EVENT <DIR> (event/ofe output files)
\OUTPUT\WINTER <DIR> (winter routine output files)
\OUTPUT\YIELD <DIR> (plant yield output files)
\OUTPUT\ERROR <DIR> (error/warning output files)
\OUTPUT\SINGLE <DIR> (single-storm output files)
\OUTPUT\SUMMARY<DIR> - soil loss summary output files)
\OUTPUT\SOILS <DIR> (water/plant/soil output files)
\OUTPUT\RANGE <DIR> (rangeland/animal output files)

Other WEPP Related Files Obtainable via Internet:

The anonymous FTP logon to "soils.ecn.purdue.edu" can also be used to obtain some other related WEPP programs, data files, and documents.

/pub/wepp/cligen-contains the CLIGEN executable program, stations file, and the state database files for the United States. The user needs to copy the state data files of choice (TX for example, for Texas) to their WEPP\DIST\INPUT\CLIMATE directory.

/pub/wepp/cligen/maps-contains the WEPP Climate File Builder interface state map files. The user needs to copy the state map files of choice (TX.* for example, for Texas) to their WEPP\DIST\INPUT\CLIMATE\MAPS directory.

/pub/wepp/document-contains the WEPP User Summary Document for the current version (94.3) in a REPLICA executable file, which must be executed under Microsoft Windows. To obtain the User Summary, put this file on the hard drive on your PC, start up Microsoft Windows, then from the Program Manager File Options, select "Run" and enter the REPLICA file name (DOCUMENT.EXE) The REPLICA viewing program will be installed on your PC under Windows, and you will automatically be put into viewing the User Summary Document. You can also print part or all of the document using REPLICA. REPLICA is a Microsoft Windows Application made by Farallon Computing Inc., Alameda, California.

/pub/cpids-contains the CPIDS (Crop Parameter Intelligent Database System) programs. These programs can be used to develop WEPP and RUSLE plant growth parameters for plants not in the default lists. See the CPIDS directory for more information.

Appendix B: Wind Erosion Prediction System Application to DOD Lands

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Introduction

Wind erosion is a particularly serious problem on many lands, including some of those on military installations. Wind erosion impacts the environment and human activities both on-site and off-site. To adequately predict the consequences of various land management strategies on wind erosion, new technology is being developed. The U.S. Department of Agriculture has appointed a team of scientists to take a leading role in development of a Wind Erosion Prediction System (WEPS). The technology development team also includes representatives from potential user groups, such as the Natural Resources Conservation Service, Bureau of Land Management, and the Environmental Protection Agency to help ensure that the technology will meet user requirements. This report presents an overview of WEPS model structure for cropland applications (Hagen, 1991; Hagen et al., 1995) and a list of enhancements needed for application of WEPS to disturbed lands.

WEPS Model Structure

WEPS is a daily simulation model written in FORTRAN 77. In WEPS, the simulation region will be a field or, at most, a few adjacent fields (Figure B1). Subregions within the simulation region denote areas which have soil, crop, or management which differs from other subregions. Surface conditions in each subregion are simulated independently from other subregions.

* Contribution from the USDA-ARS in cooperation with Kansas Agric. Exp. Stn. The modular structure of WEPS also will facilitate model maintenance, as new technology becomes available. In general, the submodels are based on the fundamental processes occurring in the field. Extensive experimental work is being carried out simultaneously with model development in order to delineate parameter values of the various processes.

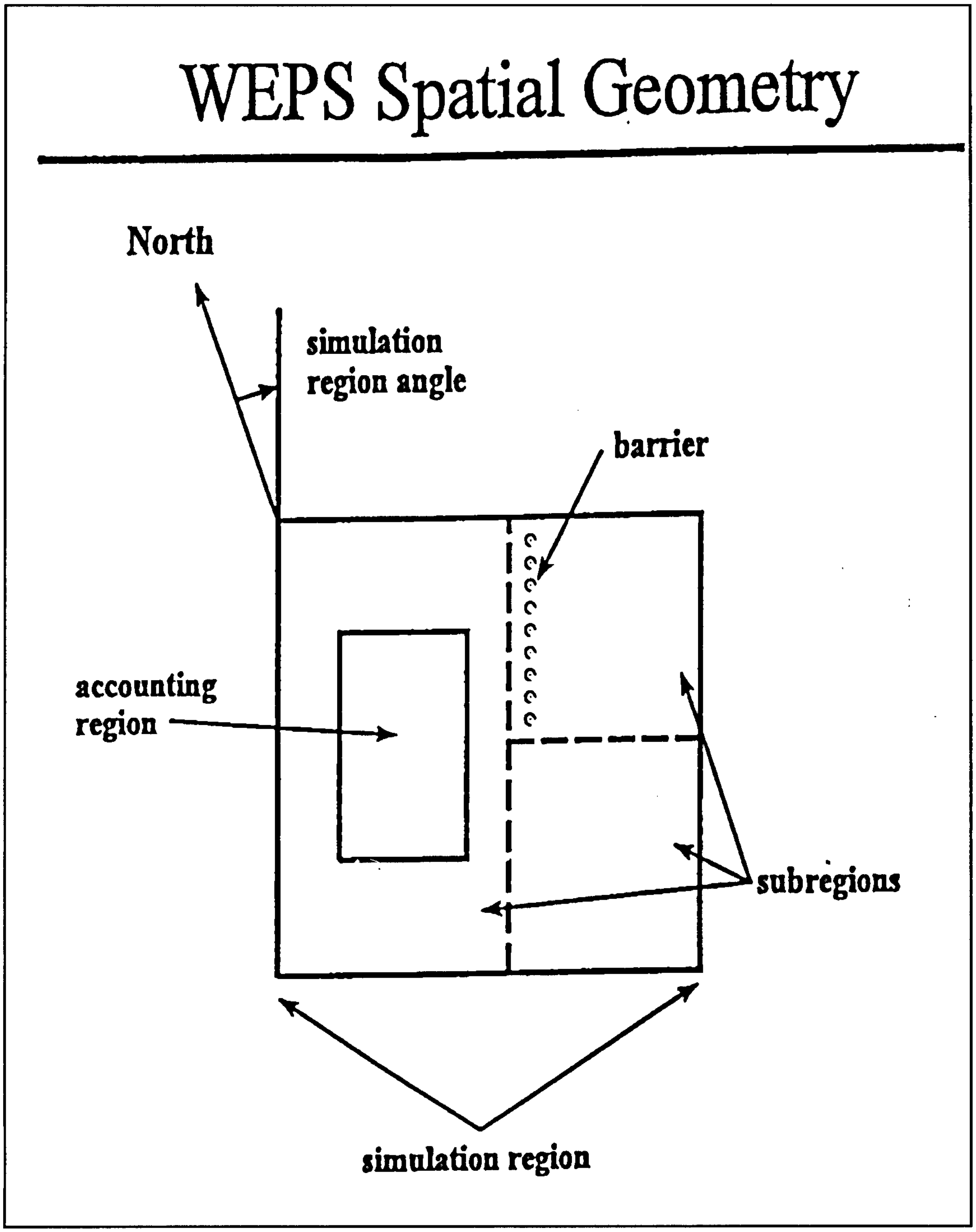

Figure B1. Simulation region geometry. End points of barriers and opposite corners of rectangular simulation region, subregions, and accounting regions must be input by user.

WEPS output is average soil loss/deposition over user-selected time intervals and accounting regions within the simulation region. WEPS also has an option to provide users with individual loss components for soil size fractions in creep-saltation and suspension. This option is particularly useful to aid users in assessing probable off-site impacts.

The structure of WEPS is modular and consists of a user-interface section, a MAIN (supervisory) program, seven submodels, and an output section (Figure B2). The user-interface section, written in C language, provides menus to facilitate preparation of input run files. Files to run the model can be created by direct recall and editing of prior run files, or by assembly of previously prepared submodel and data base files. Another important function of the user-interface is to provide a list of user-selectable output options.

Submodel Functions

The WEATHER submodel generates meteorological variables to drive the CROP GROWTH, DECOMPOSITION, HYDROLOGY, SOIL, and EROSION submodels. Using monthly statistical data in the climate data base, WEATHER generates daily values of duration, intensity, and amount of precipitation; maximum and minimum temperature; solar radiation; dew point; and wind direction and maximum wind speed. On days with wind erosion, sub-hourly wind speeds are also generated.

Biomass accounting in WEPS is accomplished by the CROP GROWTH and DECOMPOSITION submodels. Crop growth is simulated by a generalized model, which calculates potential growth of leaves, stems, roots, and yield components. The potential growth is modified by temperature, nutrient, and moisture stresses. The DECOMPOSITION submodel predicts the biomass residues in standing, flat, and buried categories. In addition, it converts standing residues to flat residues over time. There is also a biomass sink called harvest, initiated by the MANAGEMENT submodel, which removes biomass from some of the categories.

The CROP data base contains information on a wide range of specific crops and includes parameters on growth, leaf-stem relationships, decomposition, and harvest.

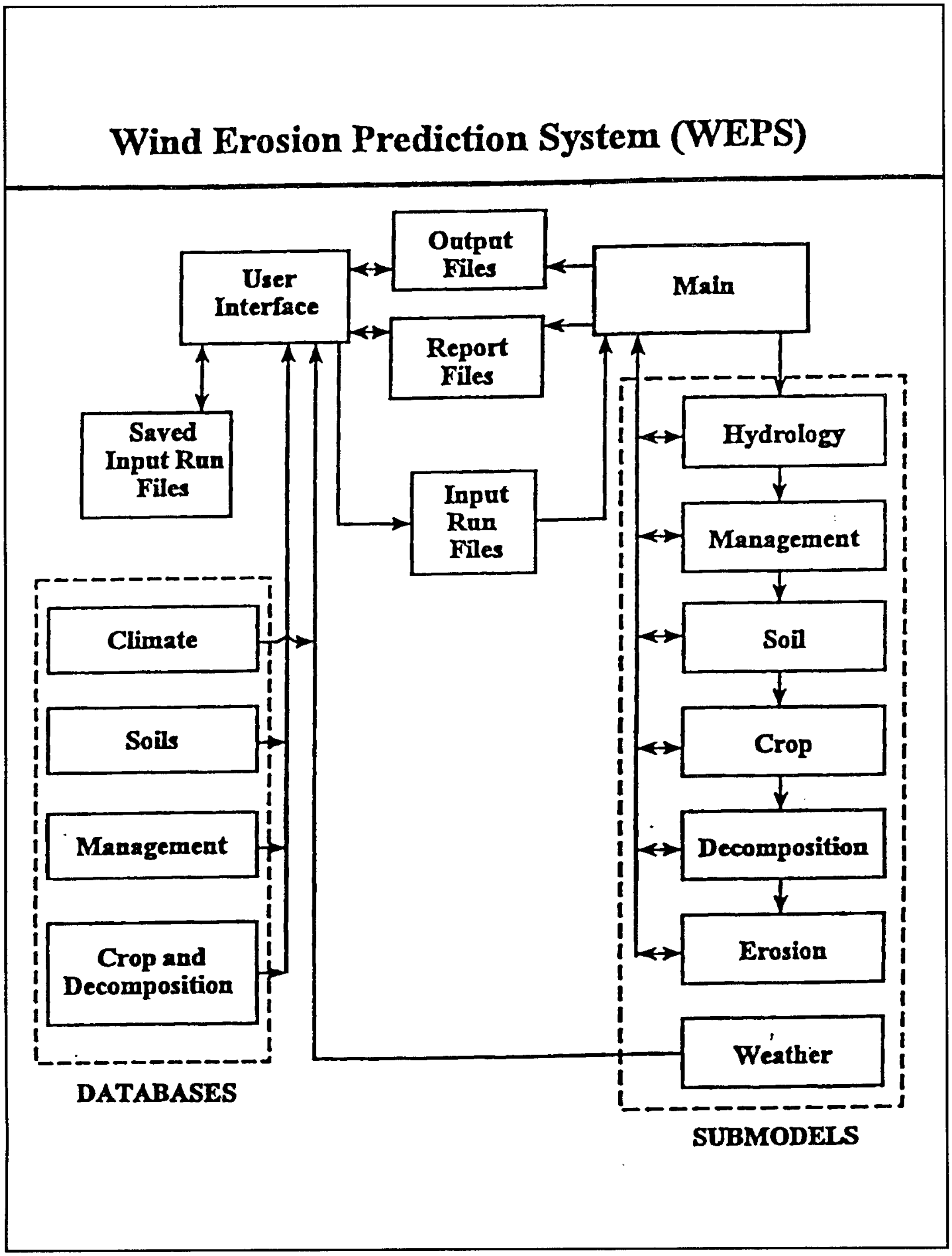

Figure B2. Diagram of WEPS structure illustrating data bases used for the input run file and sequence in which the submodels are called by the supervisory routine, MAIN.

The SOIL submodel predicts the temporal soil profile properties between erosion and management events. The soil surface is treated as having both oriented and random roughness components, which are updated separately. The SOIL data base

consists of intrinsic soil properties that are needed in predicting the temporal soil properties.

The HYDROLOGY submodel simulates the soil water balance and soil temperature, including soil freeze/thaw cycles. Snowmelt and redistribution, as well as irrigation, are simulated in this submodel.

The MANAGEMENT submodel modifies the soil temporal properties, random surface roughness, and the biomass distribution. Spacing and orientation of tillage ridges will be input by the user. The MANAGEMENT data base consists of parameters for specific tillage and harvesting machines as well as other management activities.

The EROSION submodel simulates soil loss and deposition during periods when wind speed exceeds the erosion threshold. Soil transport by the wind is modeled as the conservation of mass of two species (saltation- and creep-size aggregates) with two sources of erodible material (emission of loose soil and abrasion of clod/crust) and two sinks (surface trapping and suspension) (Figure B3).

Enhancements for Disturbed Lands

Several enhancements are needed to adapt the cropland version of WEPS to disturbed lands. These enhancements include adding parameters to the WEPS data bases, providing additional capabilities in the submodels which simulate surface conditions, and modifying the EROSION submodel to accommodate non-uniform standing biomass.

For some installations, wind statistics for additional sites need to be summarized and added to the climate data base. In locations with large orographic effects, additional sites for other climate factors also may be useful. Improved simulation of the airflow in complex terrain is also needed.

In the crop/decomposition data base, parameters for range species must be added. In some cases, additional data collection may be needed to obtain the required parameters. Capabilities to input initial conditions for growing plants must be added to the user-interface. In the CROP submodel, capability must be added to simulate multiple, competitive growing species, rather than single species.

In the management data base, parameters for such processes as selective burning, selective grazing, chaining, pitting, spraying, trampling, military vehicle traffic, and

construction activities must be added. In addition, functions to simulate these processes must be added to the MANAGEMENT submodel.

In the SOIL submodel, simulation of the soil temporal properties in response to processes occurring in arid/semi-arid regions needs improvement. On cropland, the EROSION submodel simulates erosion for standing biomass that is uniformly distributed. Hence, EROSION must be modified to simulate for biomass that has random or clumped distributions, which is typical of disturbed lands.

Conclusions

The widespread availability of personal computers offers a unique opportunity to deliver comprehensive WEPS technology to conservation planners and policy makers in the form of computer programs and associated data bases. A cropland version of WEPS will be available for testing in 1996. However, additional enhancements are needed to make WEPS fully functional on disturbed lands where there are large, non-uniform spatial gradients in surface conditions.

References

Hagen, L. J."A Wind Erosion Prediction System To Meet User Needs," *J. Soil Water Conserv.* Vol 46, No. 2 (1991), pp 106-111.

Hagen, L. J., et al. "Wind Erosion Prediction System: Technical Description." *Proc. WEPP/ WEPS Symposium, August 9-11 1995* (Soil and Water Conservation Society, Ankeny, IA, 1995).

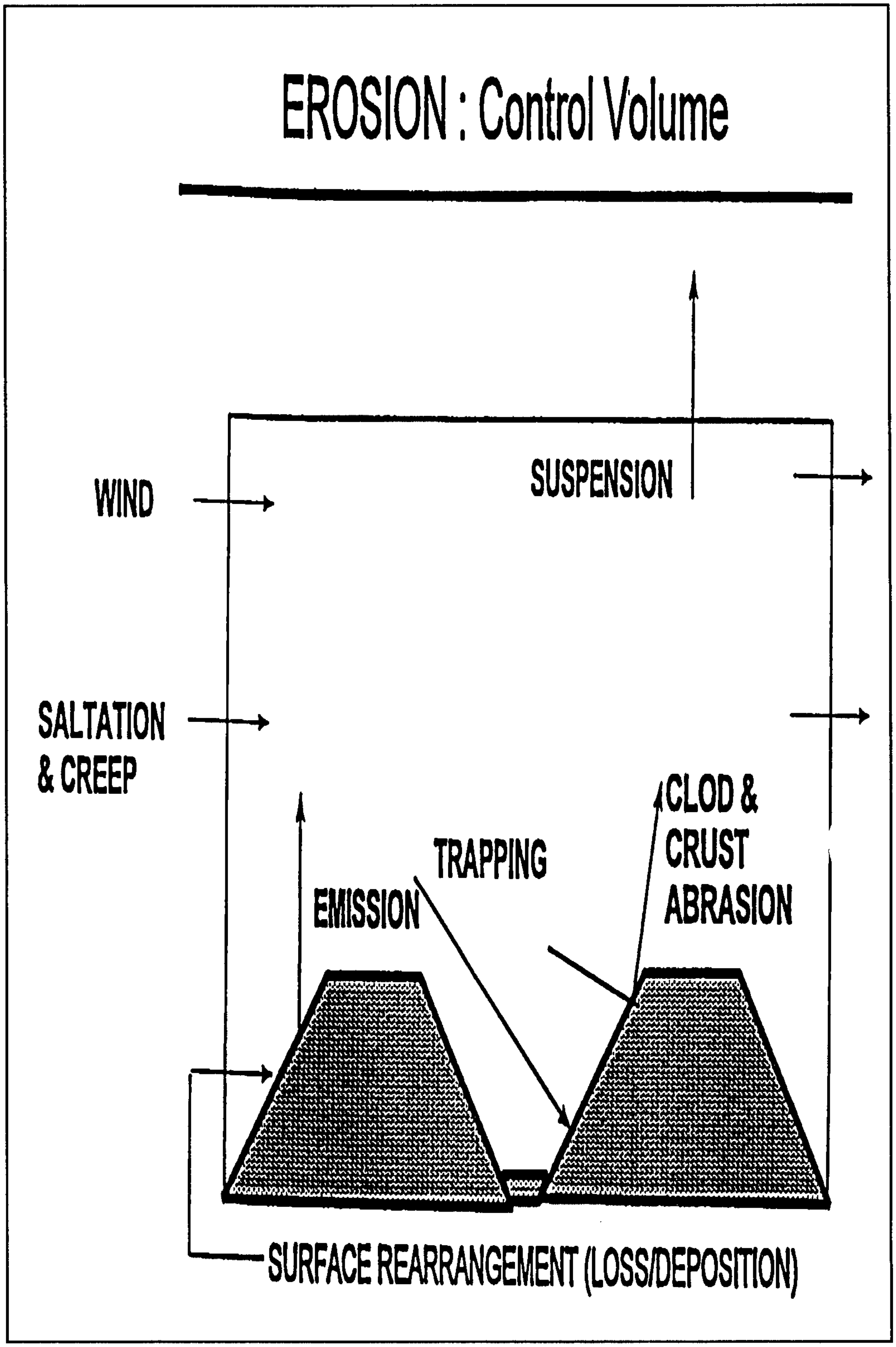

Figure B3. Diagram of control volume for EROSION submodel illustrating conservation of mass for saltation and creep with sources (emission and abrasion) and sinks (trapping and suspension).

Appendix C: The Revised Wind Erosion Equation

D.W. Fryrear
USDA Agricultural Research Service
Big Spring, Texas

The Agricultural Research Service has been conducting research on wind erosion control practices since the Great Plains Dryland Field stations were established in the early 1900s. In the mid 1940s, a team of wind erosion scientists was assembled to conduct field and laboratory research on wind erosion processes and control strategies. The Wind Erosion Equation (WEQ), developed from Great Plains data and published in 1965, was the culmination of this effort. The WEQ was to aid in designing conservation systems.

With the passage of the 1985 Food Security Act (FSA), the estimates of erosion were used to determine the farmers compliance and eligibility for government programs. With the passage of the FSA the need for accurate estimates of erosion was emphasized and the development of the Wind Erosion Prediction System (WEPS) was initiated. In 1991, the request was made for the Revised Wind Erosion Equation (RWEQ) that would utilize advanced technology from WEPS. The initial version 3.06 of RWEQ was completed in 1993 with versions 5.01 and 5.02 completed in 1995.

The basic form of RWEQ is

Average Soil loss = WEATHER X SOIL X CROP X MANAGEMENT [1]

Within the weather factor are the following terms:

WEATHER FACTOR:

- Wind velocity above threshold,
- Wind direction,
- Wind preponderance,
- Air density,
- Average air temperatures,

Solar radiation,
Days with snow cover,
Rainfall amount,
Rainfall erosive intensity (EI),
Number of rain days, and
Irrigation (amount, rate, number of irrigation days).

Soil texture and soil surface conditions are extremely important in describing erosion by wind. The intrinsic properties cannot be modified, but the temporal properties may vary within a short time interval. In RWEQ soils are modeled with the following parameters:

SOILS:

Soil erodible fraction,
Soil wetness,
Oriented roughness,
Random roughness,
Soil roughness decay,
Soil crust factor, and
Surface rock cover.

The quantity and orientation of crop residues in the field will have a significant impact on soil erosion by wind. To accurately estimate soil erosion, the crop residue levels and crop canopy must be described. In RWEQ the crops are modeled with the following:

CROPS

Flat residues (percent soil cover),
Standing residues (what will the wind see),
Crop canopy, and
Residue decomposition.

To test the relationships in RWEQ, field measurements of soil erosion were compared with estimates of soil erosion. Erosion from farmer/cooperator fields 200 meters in diameter has been collected in Scobey, Lindsey, Havre, Montana; Sidney, Nebraska; Akron, Eads, Colorado; Mabton, Prosser, Washington; Fresno, California; Portales, New Mexico; Fargo, North Dakota; Crookston, Swan Lake, Minnesota; Hancock, Wisconsin; Crown Point, Indiana; Kennett, Missouri; Elkhart, Kansas; and Big Spring, Texas.

To test that the method of combining the various factors is correct, measured soil losses for individual erosion events were compared with estimated losses using equation [1]. The agreement is illustrated in Figure 1. This is verification that the RWEQ model will describe the relationship between the various parameters and soil erosion. It is not possible to sample all combinations of parameters in field conditions where the weather conditions cannot be controlled. The values represented by the events in Figure 1 cover a broad range of wind, soil, and crop conditions.

Comparison between measured and estimated soil loss have been completed for five locations. These values are for a single erosion season usually covering 5 months.

Location	Measured (kg/m^2)	Estimated (kg/m^2)
Big Spring, TX	17.66	18.33
Elkhart, KS	13.52	12.11
Sidney, NE	3.20	3.79
Eads, CO	2.44	2.52
Kennett, MO	3.56	2.61

The data analyses are continuing, and when completed all 260 erosion events will be tested with RWEQ. Routines for wind barriers and landscapes (hills, valleys, and knolls) will be added and version 5.03 of RWEQ will be released to the public in the fall of 1995.

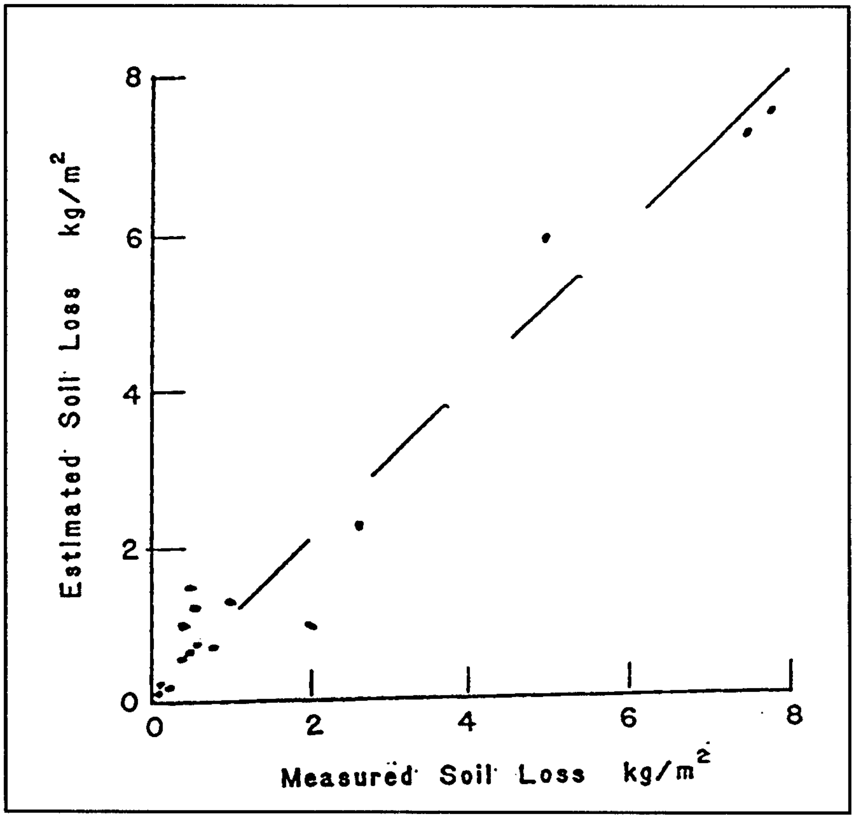

Figure C1. Estimated soil loss using RWEQ and measured soil loss from 2.5 hectare circular fields in Big Spring, TX; Mabton, WA; Elkhart, KS; Kennett, MO; and Eads, CO.

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